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Photomicrographs of Varnished Cloths

All taken at the same magnification (90 dias.), with polarised light and crossed nicols. Photomicrograph 7, for varnished glass silk, was taken with open nicols to show the construction of the textile support, which otherwise was difficult to detect.

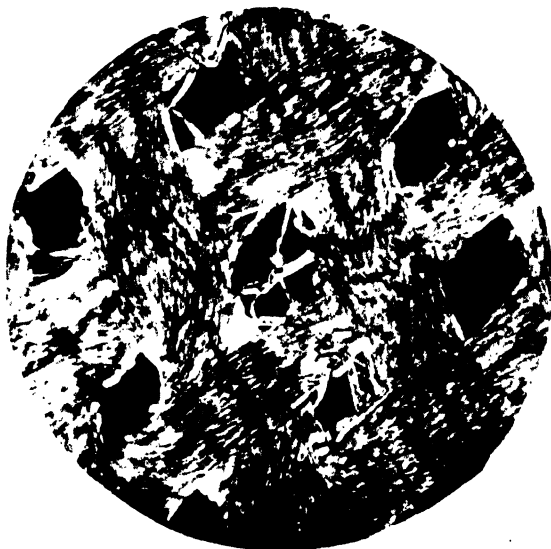
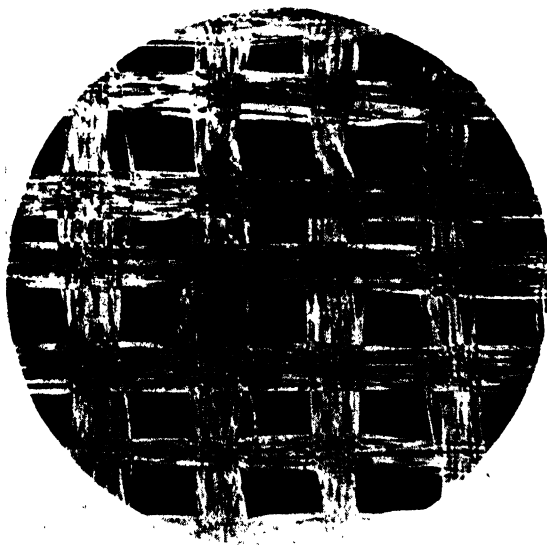


FIG. 1. Varnished calendered cotton.



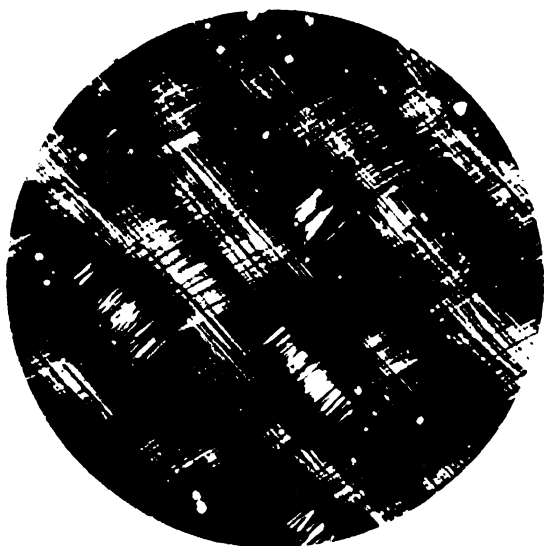


FIG. 3. Varnished cellulose acetate silk.



FIG. 4. Varnished viscose silk.

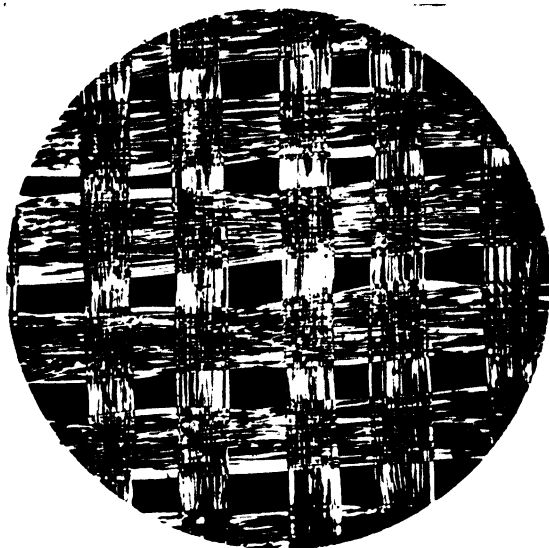


FIG. 5. Varnished cuprammonium silk.

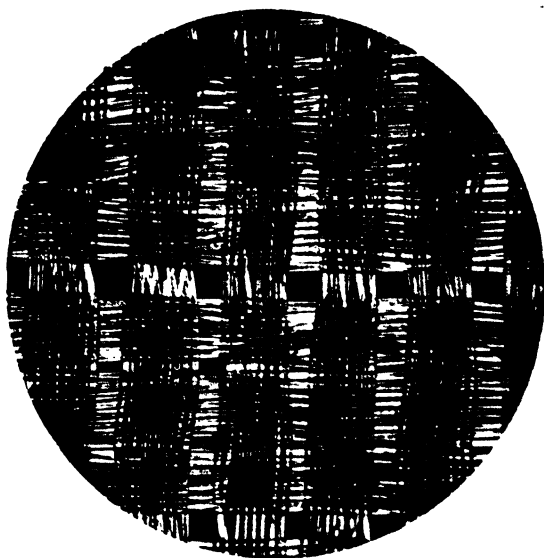


FIG. 6. Varnished nylon silk.

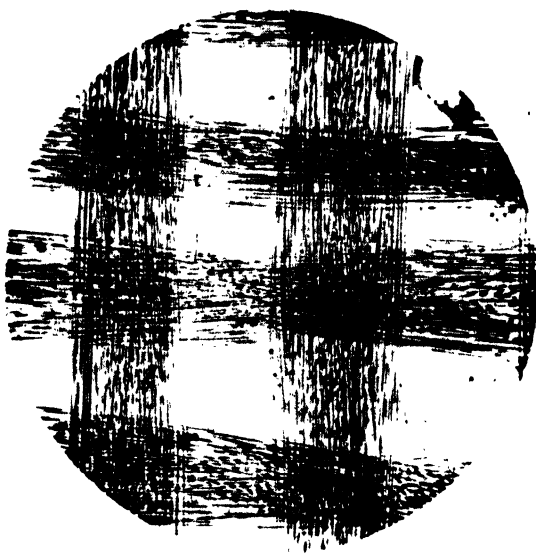


FIG. 7. Varnished glass silk.

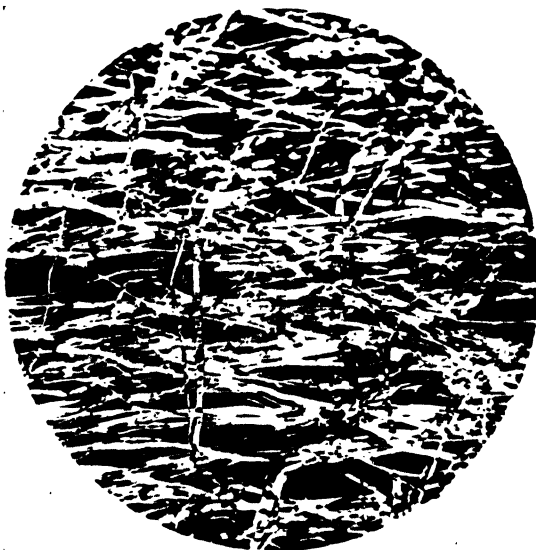


FIG. 8. Varnished gampi tissue paper.

VARNISHED CLOTHS FOR ELECTRICAL INSULATION

By

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With 60 Illustrations



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AUTHORS' PREFACE

THE authors feel that flexible electrical insulators, as typified by varnished cloths and silks, have now reached such an important stage in their development and usefulness that they merit specialised treatment.

With modesty, and not without some trepidation this little volume has been written. It has been prepared with several objects in view, and embraces a fairly wide field.

We have tried to tell the textile manufacturer something of the processes his fabrics undergo subsequently, and the properties desired in the ultimate product; the varnish maker, something of the textile supports on which his varnish is applied, and how his varnish contributes to the evolution of a flexible electrical insulator; the proofer, a little of the two raw materials he handles daily—the varnish and the fabric—and the requirements of his finished product; and finally, the electrical engineer and designer, something of a material which he is using in ever-increasing amounts.

In a few places we have indulged in criticism, and this we have tried to make constructive, for we believe that the ideal varnished cloth has not yet been devised. There is in the United Kingdom already a small army of technologists engaged in research upon this problem, and the authors themselves have perhaps been able to contribute a little to the accumulating store of knowledge.

The powerful aid of the microscope and its accessories has been enlisted where the unaided human eye has failed; it is believed that the microscope is one of the most valuable instruments for analysis and research, and is only too often disregarded or forgotten.

Whatever value this volume may have is due in no small measure to the numerous unselfish people who unstintingly offered help and advice; and in particular, to Mr. J. Milligan, of Messrs. M. Barr & Co., Glasgow, who immediately offered assistance. Its shortcomings are the responsibility of the authors. Encouragement has been given by the employers of both authors, and they are placing on record herewith their gratitude.

Mr. B. J. Nicholson, of Messrs. Jenson and Nicholson Ltd., has placed the facilities of the Varnish Research Laboratory at the disposal of the authors, which has enabled them to make different types of impregnating varnish, and to test their electrical

properties under various conditions. Mr. R. K. Fleming, of the Igranic Electric Company, Bedford, has also simplified our efforts by permitting the use of similar laboratory facilities. The authors' thanks are due also to Mrs. D. J. Chatfield and Mr. R. N. Pack for undertaking the task of typing the manuscript, in addition to their everyday duties ; to Mr. G. Campbell for several drawings ; and to all those who supplied photographs, diagrams and other information for publication.

H. W. C.

J. H. W.

FOREWORD

I

IN compiling a book of reference dealing with Varnished Cloths for Electrical Insulation, the authors have attempted to fill a gap which, for a long time, has required filling, in connection with the raw materials and intermediates used in the Electrical Industry. Dr. Chatfield, by reason of his long and intimate experience of this subject, is particularly well equipped to handle it, and I am sure that those interested in this type of production will find much matter of considerable interest. The production of Varnished Cloths is likely to be greatly developed in the future, and Industrial Varnish Manufacturers recognise that it deserves special technical treatment. The study of this work merits the special attention of those interested in this branch of industry.

R. J. NICHOLSON,

Messrs. Jenson & Nicholson Ltd.,
Paint, Varnish, Enamel & Cellulose
Lacquer Manufacturers,
London, E.15.

II

Varnished Insulating Fabrics are exacting but adaptable materials, calling for scientific background and applied technical skill in their manufacture, and in their use as components of electrical assemblies. Their selection and development are facilitated by a knowledge of their properties and by collaboration between producers and users.

The authors have made a commendable and courageous contribution to the general knowledge of these materials. They have collected information which was formerly scattered throughout technical and trade literature. They have added data from their own researches and have included thoughts which are both constructive and provocative. The result is worthy of the attention of all concerned with flexible electrical insulators.

J. MILLIGAN,

Messrs. M. Barr & Co. Ltd.,
Varnished Cloth Manufacturers,
Miller Street, Glasgow.

III

Development in the Electrical Industry to-day tends more and more towards reduction in the size of components. This brings in its train the need for higher-grade insulating fabrics and varnishes. Hitherto the manufacturers of textiles, varnishes and electrical apparatus have carried out their individual researches on their own products, and there has not always been complete collaboration and exchange of technical data so obtained.

In this book the authors have given the results of their investigations into the use of various fabrics, and methods of impregnation, in providing high-class insulating materials. Microscopic examination of thousands of samples has brought to light many previously unknown factors, and the authoritative data given in the book should be of the greatest value to the industries concerned.

R. K. FLEMING,
Igranic Electric Co. Ltd.,
Bedford.

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VARNISHED CLOTHS FOR ELECTRICAL INSULATION

CHAPTER I

INTRODUCTION

FLEXIBLE insulators as typified by varnished cloths, are of considerable importance in the manufacture of many types of electrical components and machines. These flexible insulators are built up on a variety of textile supports with widely varying properties. Furthermore, the impregnants or varnishes used to seal up their interstices can also vary widely in their electrical properties, so much so, that in spite of extremely careful application, the net result may be almost valueless from an electrical point of view. The efficiency of a flexible insulator may be also seriously reduced by faulty or careless application of an eminently satisfactory impregnant on a first-class textile support.

It is at once apparent, therefore, that satisfactory varnished cloths for electrical purposes are the result of a succession of highly skilled processes. Laxity in any one of these processes means, at best, reduced electrical insulation, or at worst, complete failure.

The discriminating user of varnished cloth is entitled to enquire if the products he buys on the open market are entirely satisfactory for the uses envisaged, and moreover, good as they may be, whether they are capable of further improvement. In all fairness to the second question, the answer must be given that generally they are not entirely satisfactory, and with patient research are capable of substantial improvement. Of course, varnished cloths which approach nearer to the ideal than others are available, but diligent searching and scientific testing are necessary to discover them.

When the user of varnished cloth casts doubts on its quality, those who are responsible for its manufacture are compelled, in turn, to interrogate themselves.

Firstly, they may ask, is the composition of the supporting textile ideal? Which of cotton, natural silk, viscose, cuprammonium rayon, cellulose acetate or other cellulose ester, nylon, asbestos, or glass fabric, is the most suitable base for impregnation?

Is the actual construction of the fabric the best that can be devised? Would mixtures of the above materials in the form of individual threads, or as threads containing mixed filaments give improved results? Are the methods of scouring and finishing the woven fabric prior to its reception of the impregnant satisfactory?

Has sufficient attention been given to the formulation of the impregnant? Has it maximum penetrating properties? Can its dielectric strength, especially under moist conditions or at elevated temperatures, its ageing properties, its resistance to decomposition by heat, its tendering effect on the fabric, its resistance to disintegration under hot humid conditions, or its resistance to oils, ozone, and oxides of nitrogen, be improved?

Finally, has the last word been said about the effectiveness of present methods of impregnation with the impregnant?

All these questions are relevant and require answers, but complete answers can be obtained only if there is all-round co-operation. At least four different classes of people are involved in the manufacture of varnished cloth, and they have their own particular problems to solve, their own adjustments to make, or their requirements to state. They are :—

1. The textile manufacturer :—
 - (a) Spinner.
 - (b) Weaver.
 - (c) Cloth finisher.
2. The impregnant or varnish manufacturer.
3. The proofer or manufacturer of the varnished cloth.
4. The users of varnished cloth in the electrical industry.

The best varnished cloth can be produced only as the result of constant and open co-operation between the four classes. It is of fundamental importance to know precisely what properties the electrical industry requires before real progress can be made. It is obviously the first essential step before any successful scientific investigation is started, to know both exactly and fully what the investigator is expected to achieve. Without a concise object in view there is much floundering in the darkness and a considerable waste of time.

Once the object is known, there is not much more the proofer can do after he has achieved ideal conditions of application and drying. The solution of the problem is then the onus of the textile and varnish manufacturers, and in the long run the investigation often becomes the sole responsibility of the latter. There is,

however, an increasing number of reputable varnished insulating cloth manufacturers, who, in addition to assessing users' requirements, institute research and co-ordinate the efforts of the individual processors.

The authors of this book, one of whom is associated with a varnish manufacturer, and the other with a manufacturer of electrical components and equipment, have sought, in a modest way, to compile a useful record of the manufacture and properties of varnished cloths, and to answer some of the many questions enumerated above. Where answers have not been found, the authors hope they may have been the means of stimulating interest leading to a solution, or perhaps may have supplied an unconscious clue to it.

The present requirements of varnished cloths vary considerably according to the uses to which they are put. The following is a list of most of their important properties.

1. Homogeneity. The varnished cloth must be homogeneous in character, that is, free from extraneous matter such as dust and grit, stray filaments of textile or neps, and disintegrated oxidised or gelled agglomerates from the varnish.

2. Smoothness. Freedom from mechanical damage, pinholes, bare patches, etc. It should have a smooth even surface, as free as possible from the undulations which are characteristic of fabrics of certain type, or which are caused by the use of a wrong type of impregnating varnish. It should be free from wrinkling, rivelling or webbing; free from crater formations or cissing arising from the use of excessive lubricant in the varnish or for other reasons; free from mechanical damage resulting from bad control of the proofing process, possibly accentuated by faulty formulation of the varnish or by faulty yarn or cloth; and free from pinholes or bubbles, bare patches, and runs or tears.

Irregularities in the surface are liable to occur at the beginning and end of pieces, and these should be avoided. There is also a tendency for the film to build up at the edges, and this should be minimised or these strips eliminated. Unevenness in finished material may arise from rough basic cloth or cloth which has been badly creased before impregnation.

3. Satisfactory Impregnation. The varnished cloth should be impregnated so that each individual filament of each piece of thread is enveloped in impregnant, or is sealed completely up to the points of contact in the case of tightly-spun filaments. Voids should be absent.

4. Flexibility. The varnished cloth should have regular hardness and toughness throughout its entire thickness, and adequate flexibility. In other words, there should not be a thin layer of hard film at the air-cloth interface, with a soft or semi-liquid underlayer.

The flexibility of the insulating fabric should be such that it can be lapped round components of small dimensions or wire, if required, at ambient temperature, without exhibiting signs of fracture at the external surface of the bend or disruption inside the bend. The fabric should permit of bending through an angle of 180 degrees round a $\frac{1}{8}$ inch mandrel. Sometimes electrical equipment is used at very low temperatures and therefore the possibility of serious embrittlement under these conditions must be borne in mind also.

5. Freedom from a Tendency to Damage by Creasing. The varnished cloth should be supplied for use free from creases, for bad creases cause serious damage to the film of dry impregnant. There is not yet available, in the authors' experience, a varnished cloth which will resist a double fold under pressure without exhibiting a fracture at the point where the folds converge. A varnished cloth which will resist rough handling, involving bad creasing, without showing signs of film disruption, is an accomplishment of the future.

Varnished cloth which has a low natural rigidity is more readily crushed and creased than impregnated starched cotton fabric. Varnished silks are typical examples of fabric with low rigidity, and they are very susceptible to damage by crushing. A good electric strength should be maintained after crushing; in other words, the film should not easily suffer mechanical damage by this treatment.

6. Resistance to Mechanical Damage. Abrasion Resistance. The varnished cloth should be tough and resistant to accidental mechanical damage; thus it must withstand a reasonable blow or permit dragging over a blunt edge without fracture or disintegration of the film. It must also be as resistant as possible to abrasive action. With the normal type of varnished cloth which is substantially free of surface tack, it is the exposed surface which must possess good resistance to mechanical damage. With the adhesive type the exposed surface cannot be expected to possess both adhesive properties and such good resistance to mechanical damage, but it is essential that the layer of dried impregnant underneath the adhesive layer has good resistance.

7. Absence of Excessive Tackiness. The material must be capable of being unrolled without damage. This means that the exposed surface of the fabric must be substantially free of surface tack, so that adjacent surfaces, pressed together while in roll form, separate easily. If serious adhesion between these surfaces occurs, then one or other may suffer from "picking out" of the impregnant from the raw cloth when force is applied to separate them.

This means that excessive adhesiveness must be absent, not only at English ambient temperature, but also at more elevated temperatures. Rolls of insulating fabric may be stored under abnormally hot conditions, or shipped through the tropics.

Adhesive varnished cloth must also be capable of being unrolled, but in this case damage to the top surface is not of fundamental importance from an electrical point of view. It is, however, essential that the basic film upon which reliance is placed for electrical insulation remains intact.

8. Colour. Colour of varnished cloth is a relatively unimportant matter. There are technical considerations in respect to it, but in addition to the usual colours, black and yellow, almost any colour desired by the electrical component manufacturer can be made without important variation of electrical properties. The subject of colour, is however, dealt with in greater detail in the section devoted to it.

9. Thickness. Thickness is important. Variations in thickness should be small and the average overall thickness should be within agreed limits. These will vary with the type of basic textile used, and the number of coats of impregnant applied.

10. Joins. Joins are a nuisance in any type of varnished cloth or tape, and generally the frequency of joins is restricted by specifications. The strength at joins should not be below an agreed figure.

11. Retention of Flexibility on Storage. The insulating fabric should be stable under a variety of conditions. It should not lose its flexibility on prolonged storage under normal conditions. There is a marked tendency for oleo-resinous impregnants to age or embrittle on storage, as the result of further oxidation.

12. Heat Resistance. It should resist embrittlement on exposure to elevated temperatures common to ordinary electrical equipment operating under reasonable conditions. For equipment operating at much higher temperatures, *e.g.*, 150°–200° C. or higher, special cloth is manufactured, and this, of course,

necessitates special impregnating varnishes and basic cloth to withstand the exaggerated conditions.

13. Freedom from Serious Tackiness Development on Heating. The varnished cloth should not develop a serious tackiness, unless this is specially required, at or above natural air temperatures, such as may be encountered during the manufacture of components, etc., or during their subsequent operation in use. Thermoplasticity should be avoided at all costs.

14. Stability. The film of varnish should not disintegrate on prolonged storage, as evidenced by liquefaction and excessive tackiness or stickiness. A satisfactorily resistant varnished cloth is not difficult to achieve, to suit the normal atmospheric influences as experienced in Great Britain or most parts of Europe, but if varnished cloth is to be stored under tropical conditions of high humidity, special impregnants and processing treatment are essential.

15. Tensile and Tearing Strengths. The tensile and tearing strengths of the varnished cloth should be high, and these should be maintained after prolonged storage, or after heating, such as is encountered during the operation of equipment. Again, cloths likely to be stored or used under tropical conditions need special consideration.

16. Resistance to Transformer and other Oils, and Chemicals. Resistance to Impregnants and Adhesives. The varnished cloth should be resistant to transformer oils, and similar materials, both at ordinary and elevated temperatures if specified. When unusual resistance to chemical fumes is required, special cloths are necessary. Where the varnished cloth is used for taping cables, it should be resistant to the action of any compound used between layers to exclude air and moisture, or to adhesives such as Chatterton's compound. Similarly varnished cloth should resist attack by impregnating varnishes, if the cloth is involved in the manufacture of coils, chokes, transformers, etc., which are subjected to vacuum impregnation with varnish, or which are immersed in varnish.

17. Resistance to Ozone. Varnished cloths should possess good resistance to ozone, but this aspect is still the subject of research.

18. Resistance to Oxides of Nitrogen. Coupled with resistance to ozone is resistance to disintegration by oxides of nitrogen which may be produced simultaneously with ozone.

19. High Dielectric Strength under all Conditions. High dielectric strength under varying conditions is of paramount

importance. Firstly the cloth must possess high dielectric strength under normal conditions, for if this is not the case it is useless to consider it for use under more exacting conditions. The dielectric strength should be substantially maintained at elevated temperatures such as are normally encountered in working plant, and also should not drop below a minimum safe value under conditions of high humidity.

20. Resistance to Disintegration by Maintained Electric Stress. The varnished cloth should withstand a high maintained electric stress for an agreed period of time.

21. Retention of Electric Strength under a Tension. Since considerable amounts of cloth are used in a state of tension, it is imperative that insulating properties are not destroyed because of resulting mechanical damage to the film of impregnant. When varnished cloth, in the form of tape, is used for the binding of cables, it is essential that it withstands the extension caused by bending the cable, without damage, either when the cable is wound round drums or when it is laid.

22. High Heat Transfer Coefficient. It is often a great advantage to run an electrical machine at an elevated temperature, and if this is to be done satisfactorily it is essential that any heat generated internally has every chance of dissipating itself rapidly to avoid dangerous local overheating. This implies that the heat transfer coefficient of the varnished cloth used must be high—a property depending on the constituents of the varnish and the efficiency of the impregnation.

23. Freedom from Risk of Spontaneous Combustion. The varnished cloth should be in such a state that it can be stored in rolls, reels, sheets, or any other convenient form, without fear of spontaneous combustion.

24. Low Acidity. The acidity of varnished cloth is another important property. This is usually described as the pH value or hydrogen ion concentration of the cloth. It is really a measure of the acidity of the aqueous extract obtained from the varnished cloth. The acids, therefore, are water soluble, and of a corrosive type. Varnished cloths which are highly acidic initially, or which develop acidity on ageing, may cause corrosion of copper or other metals with which they are in contact.

The list of properties enumerated above is comprehensive and it shows that the production of an entirely satisfactory varnished cloth is no easy matter. It is a process which should not be undertaken light-heartedly. It shows further that consumers

of these cloths should be extremely careful where they place their orders. There are, in existence, good manufacturers of varnished cloth with first-class technical staffs, and they are obviously the most likely to accommodate most or all of the essential requirements.

CHAPTER II

TYPES AND USES OF VARNISHED CLOTH

TYPES

Cotton

IMPREGNATED cotton fabric is commonly known as Varnished Cloth. This type of flexible insulator is available in several convenient forms, which may be enumerated as follows :—

1. Rolls, approximately 36 inches wide.
2. Bias cut tapes in various standard widths.
3. Straight cut tapes in various standard widths.
4. Separate sheets of various sizes.

According to B.S.S. 419, 1931, sheets are approximately 36 inches wide unless otherwise specified, and strip or tape is in

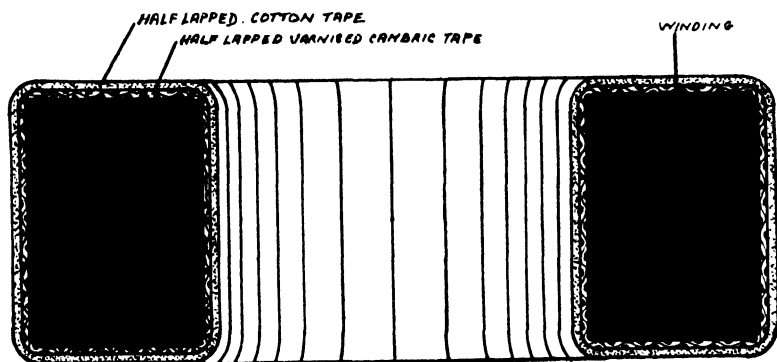


Fig. 9. Section of a taped coil for a magnetic brake or clutch, showing method of insulation.

widths up to 6 inches wide in reels. Material of width greater than 6 inches is referred to as rolls.

Varnished cloth which is cut parallel to the warp threads or the selvedge edge is known as straight cut ; cloth cut so that both warp and weft threads make the same angle with the edges of the strip or tape is known as bias cut strip or tape.

Bias cut tape is easily distinguished from straight cut tape in that it shows a greater extension, and a greater resistance to a tearing force normal to the cut edge. If bias cut tape cannot be

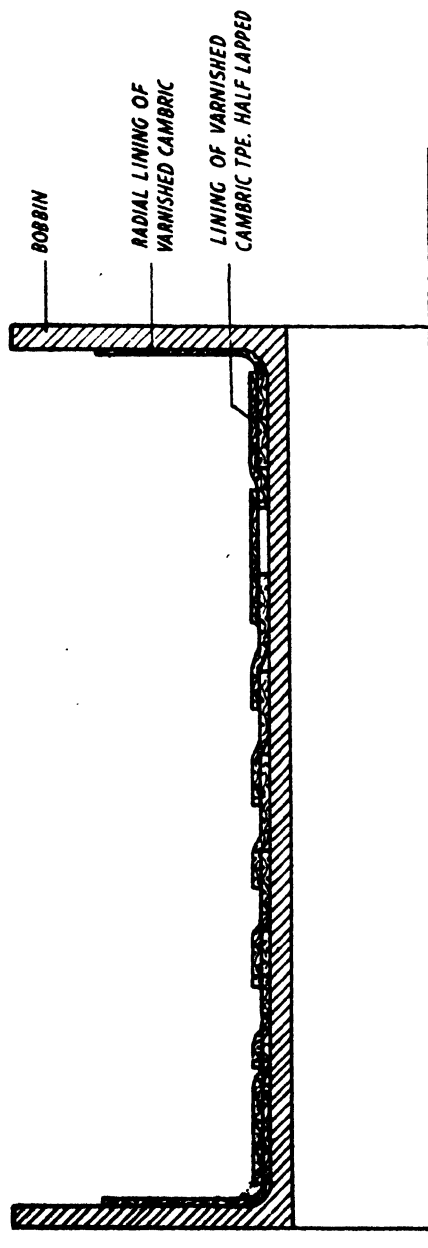


FIG. 10. Section of a bobbin showing method of lining with varnished cloth.

immediately recognised visually, it can be easily stretched by pulling with the fingers, and this simple test provides the answer. Impregnating varnishes for bias cut tape must accommodate this large extension without disintegration, which would result in loss of electrical properties.

There is another type of strip made in small widths only, which comprises solely of warp threads. These parallel threads are cemented together probably by means of a size and subsequent calendering, to produce a smooth flat strip. The threads are further held together by the application of an insulating varnish, but the strip can be fairly easily separated into thinner strips or even individual threads by tearing in a direction parallel to the threads.

Silk (Natural and Artificial)

Impregnated silks are available in similar forms to cotton, but there are at present in this country no official

standard or draft specifications controlling their properties. Where specifications exist they cover the special requirements of individual users only.

There is another form of oiled or varnished silk which is cut into short strips, for use in the manufacture of a recently introduced sleeving. Apart from its electrical properties it must possess a varnished surface with a residual "cling," so that when once rolled into cylindrical form there is sufficient adhesion between the surfaces to maintain the shape.

The basic silk fabric may be natural silk or the artificial silks such as the viscose, cuprammonium, or cellulose acetate types. Natural silk when varnished is known as "Varnished Silk"; artificial silk when varnished is referred to as "Varnished Rayon," and special grades of rayon are produced for this purpose. Prior to the recent war the basic fabric was essentially natural silk, but the cessation of supplies from Japan and elsewhere forced interest to develop in the artificial silks. In many ways the varnished rayons are not so satisfactory as the final natural silk products, but a considerable amount of research work has been conducted on the former with encouraging results. Some indications of the deficiencies of impregnated rayons, and how they have been eliminated is given in a later chapter.

Nylon. The use of nylon as a basic fabric for insulation is an obvious prophecy for post-war development. Under the present war conditions there is no nylon fabric available for insulating purposes, and any work conducted on this material for electrical purposes is, as yet, unpublished.

Glass. For high-temperature work impregnated glass silk is used, and its manufacture has caused the varnish maker to use all the ingenuity he possesses, to formulate an impregnating varnish which will allow full advantage to be taken of the outstanding heat-resisting properties of the glass fabric.

Asbestos. Fine asbestos fabric is another possibility for high-temperature work. Although unimpregnated fabric has been used as an insulating packing, there is little evidence, if any, to show that it has been used in impregnated form.

Paper. Varnished paper is another popular type of insulating material. Its detailed consideration is beyond the scope of the present volume, but much information included on varnished cloths is obviously applicable.

USES

Varnished cloths are used in the electrical industry for many purposes, and the following are but a few examples of their widespread utility and importance.

Firstly, they are used for lining bobbins, and for lining armature and stator slots.

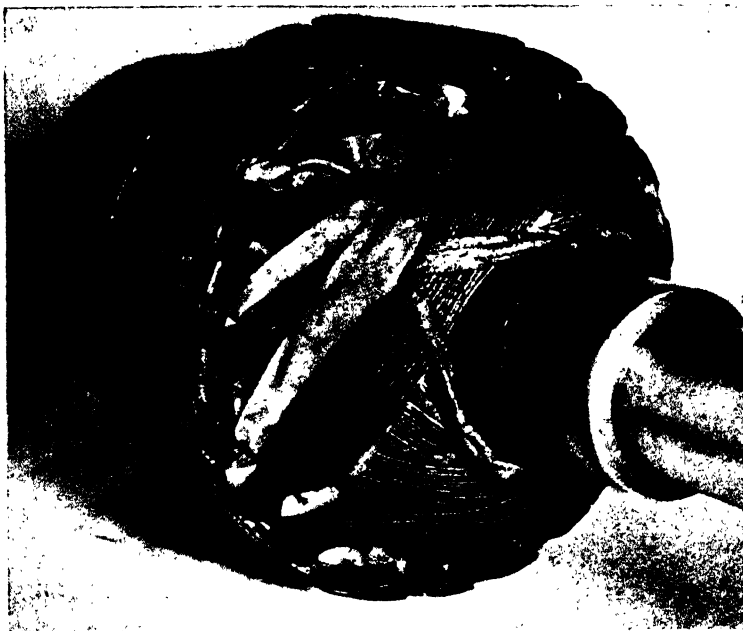


FIG. 11. Modern high-speed armature showing use of bias-cut varnished tape.

They are used also as interlayers, instead of paper, between layers of wire in coils.

Another use is for completely taping coils, or for taping the ends of armature and stator coils.

Tape is also valuable for protecting exposed joints in coils and other electrical components.

One of the most important uses is for lapping cables, and in this connection two types of strip or tape are used—ordinary substantially tack-free, or the tacky and adhesive varieties.

The adhesive type is really an ordinary impregnated tape except that the surface has received an extra coating of adhesive varnish. It is essential that the adhesiveness is maintained for long periods of time. It is astonishing how many materials, which are generally regarded as inert, lose their natural stickiness on prolonged exposure to oxidising conditions. The property of retention of adhesiveness should be checked, therefore, very carefully.

A recent development is the novel form of sleeving, already mentioned, quite unlike the popular type of impregnated braid. It consists essentially of short lengths of varnished insulating silk which are lapped round a small-diameter mandrel, lengthwise, to provide thin tubes when removed from the supporting mandrel. These tubes, which consist in fact of several layers of varnished silk, are inserted inside lengths of untreated braid. The whole is then treated with a sizing insulating varnish to cement the internal varnished silk tube to the outer supporting braid cylinder. The varnished silk used for this purpose is specially designed to have sufficient surface tack, so that when once it is rolled up and removed from the mandrel, the adjacent surfaces adhere and maintain the desired shape.

The illustrations on pp. 9, 10, 12, show some of the uses to which varnished cloths are put.

CHAPTER III

TEXTILE SUPPORTS FOR VARNISHED CLOTHS

ALMOST every fibre, whether of vegetable, animal, mineral or synthetic origin, has been converted into a textile support for the production of varnished cloths.

The four groups are subdivided as below :—

1. Vegetable Fibres

Cotton.

2. Animal Fibres

Silk.

3. Mineral Fibres

Glass.

Asbestos.

4. Rayons

Viscose.

Cellulose acetate.

Cuprammonium.

5. Synthetic Organic Fibres

Nylon.

Definitions

The following are definitions of some common textile terms. They are apt to arise in dealing with varnished cloths, and are included for the convenience of readers outside the textile industry.

Fibres or Filaments. These are the simplest elementary constituents of fabrics, and they vary in length from about an inch, to many yards, depending on the type.

Yarn or Thread. When these fibres or filaments are twisted or spun together they form yarns or threads. Dozens of filaments—may be spun together to give the required threads.

Counts. The fineness or weight of the threads is indicated from a figure, which with cotton is known as the counts. A yarn which weighs $8\frac{1}{2}$ grains per yard is said to have a count of one, and this is calculated from the fact that 840 yarns or yards weigh 7,000 grains or 1 lb. Hence, the number of yards of yarn which weigh $8\frac{1}{2}$ grains is known as the counts. Thus the higher the number of counts the thinner or finer the yarn.

Denier. This is another measure of the weight of thread, and

is a term used specifically for silk threads. One denier is the weight in milligrams of 9 metres of filament or thread. Hence the greater the number of deniers the heavier and stronger the filament or thread.

Momme. A momme is a Japanese unit of weight, and there are 7.56 mommes to the English ounce. Confusion is sometimes caused because it is written as m/m, and may be mistaken, therefore, for the m.m. for millimetre. The standard full weight of a 50-yard piece of 6 m/m Japanese silk is 288 m/m, which means that a yard length of silk weighs 5.76 m/m. Japanese silk is referred to as so many momme silk, and the higher the descriptive numeral the heavier and thicker the silk.

Fineness of Weaving. Fineness of weaving is represented by the number of threads per inch.

Ends and Picks. Threads that run lengthways, *i.e.*, parallel to the selvedge edge are called ends, and those that run widthways or at right-angles to the selvedge edge are called picks.

Warp and Weft. Warp threads are parallel to the selvedge edge and correspond with the ends. They are generally sized. Weft threads pass widthways and correspond with the picks. They are rarely sized.

Selvedge. The selvedges occur at both edges of woven fabric. The function of selvedges is to prevent the woven fabric from disintegrating in handling, and they should possess adequate strength and elasticity. Weak selvedges permit tearing during subsequent processing, and furthermore, their elasticity is equally important, for if they are too rigid the strain on a cloth under tension is not equally distributed over the entire width; the inelastic selvedge takes more than its share and splits. The ideal selvedge should be as plain and as flat as the body of the cloth.

Reed Marks. This defect is also known as reediness. It occurs when the ends run together in twos, threes or fours, down the length of the piece.

Temple Marks. These are small holes which occur on both sides of a piece of cloth, and they are caused by the pins or sharp edges of the temples piercing the cloth as the cloth passes round the rollers.

Slubs. Slubs result from uneven spinning of warp or weft yarns. The yarn is not of regular diameter, being either exceptionally thin or thick in places. Sections of the yarn which appear excessively thick are called slubs, and if the defect occurs often the yarn is described as slubby.

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Floats. These are stray lengths of warp or weft yarn left on the top of the cloth and are caused by the yarns breaking.

Neps. Neps are dead, unripe, or matted cotton fibres. They resist impregnation whether by bleaching solution, dye, or varnish impregnant, and betray themselves as white untreated spots.

Hank. A hank is a fixed length of yarn ; for cotton it is usually 840 yards, and for spun silk it is 1,000 yards.

Seconds. If pieces of cloth exhibit faults they are known as seconds.

Grey Cloth. Grey cloth is the term applied to loom state cloths.

Twist. Twist is measured in twist per inch of yarn. The twist may be either a right-handed twist or a left-handed twist. A yarn with a right-handed twist is said to be spun twist way, and a yarn with a left-handed twist is said to be spun weft way. Both warp and weft may be twisted either twist or weft way. Or the warp may be twisted twist way, and the weft, weft way, or *vice versa*.

Differentiation between Warp and Weft Threads

Since strength tests have to be conducted on varnished cloths and on raw unimpregnated fabric it is essential to be able to select warp and weft threads. The strength of the warp thread is likely to vary considerably from that of the weft, and for this reason strengths are determined in both directions.

1. If the cloth has a selvedge edge, then the warp threads are parallel and the weft threads are at right angles to it.

2. If the cloth is reedy, then the threads causing the reediness are warp threads.

3. If the amount of twist can be readily estimated, then the yarn with the greatest amount of twist is usually the warp.

4. If size can be detected in a thread by microscopical or visual examination it is highly probable that the thread is the warp thread. The weft is sized only occasionally.

5. Warp threads are generally straighter in the cloth than the weft threads.

6. If the warp and weft yarns are twisted in different directions, then the yarn spun twist way is most probably the warp and the yarn spun the weft way the weft.

Defects of Raw Fabric

Before any fabric is treated with an impregnating varnish it should be examined for the following defects. Faulty base fabric means faulty varnished cloth.

Rough Finish. The surfaces of the fabric are rough due to fine fibres or filaments projecting beyond them. The extent of the roughness can be detected by holding the fabric near the eyes and by looking along it parallel to the surfaces. The photomicrographs below show the comparative surface roughness of calendered cotton and artificial silk or rayon fabrics.



FIG. 12. Edge-on view of calendered cotton fabric showing many cotton fibres protruding from the surface. Because of the short cotton staple, this is an inherent fault. Magn. 48 dias.



FIG. 13. Edge-on view of viscose silk showing absence of fibres protruding from the surface. Magn. 48 dias.

Creases. Creases at right angles to the selvages may be eliminated during the application and drying of the impregnating varnish, because a tension is applied parallel to the selvages. This tension has the effect of opening out the creases. Creases which are parallel to the selvages, however, cannot be removed by this method and they cause serious film irregularities. The varnish tends to run down from the high edges of the creases and accumulate in the channels. All fabric for impregnation is delivered in roll form, and it is careless handling and rolling by the textile manufacturer or subsequently which cause creases.

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Joins. The fabric should be at least of a minimum practical length, and free from joins. Joins also contribute to film irregularities.

Stains. Fabrics are likely to exhibit many different types of stains, among which may be included :—

Mildew Stains. These occur in a variety of forms—yellow, green and brown—and are caused by storage under dark, warm, moist conditions with restricted air supply ; they are indications of probable weakness in the fabric at the points affected. Mildew organisms actually attack cotton and other fibres and leave, in the initial stages of disintegration, pitted surfaces. In bad cases, the cloth may be broken down into an amorphous powder. Special mildew preventatives are sometimes introduced into the fabric during the sizing process to combat this tendency.

Bleached and dyed fabrics are not so susceptible to mildew formation as grey fabrics, for the process of bleaching or dyeing often kills mildew fungus. All cotton fabrics, however finished, are liable to develop mildew under bad storage conditions, especially if no mildew inhibitors have been used.

Oil Stains. These are caused by accidental oil contamination derived from any of the processing machinery. The oil may be present on individual yarns, in which case it points to introduction during spinning. If comparatively large areas are affected then the oil may have been introduced during or subsequent to the weaving process.

Whatever their origin oil stains are bad, for they prevent penetration by the impregnating varnish into the threads and cause the impregnant to “run away” and leave bare patches. They also retard or inhibit the natural drying process of the impregnating varnish. If the film of varnish on a fabric demonstrates irregular drying—some patches having a pronounced stickiness by comparison with the rest of the film—then it is almost certainly due to oil or grease in the original raw fabric.

Rust and Dirt Stains. Their existence is too obvious to need emphasis. They are unsightly and may be apparent even after varnish has been applied to the fabric. The inclusion of mineral matter of any sort in varnished cloth is undesirable, for it is a possible cause of faulty insulation at points where it occurs.

Mechanical Damage. This includes tears, holes caused by nails used in crates, and temple marks.

Certain weaving flaws, such as occasional thinness of cloth, and unusually large spaces between adjacent warp or weft threads,

can often be eliminated or accommodated by judicious application of impregnating varnish.

Tears and large holes resulting from mechanical damage cannot be sealed by varnish, and therefore they render useless the particular cloth in which they occur.

Bad Selvedges. It has been explained already that insulating varnished cloths are impregnated and dried under tension; the part which the selvedges play is to assist in the equal distribution of this tension over the entire width of the cloth. Selvedges by reason of their construction do not possess the elasticity of the remainder of the cloth, and hence they tend to absorb more than their share of the tension. The essential features of good selvedges, therefore, are elasticity and strength. A weak selvedge means that should fracture occur there during impregnation with varnish, the sudden redistribution of the tension will cause the cloth to move irregularly over the rollers, and creases may result.

If the remainder of the cloth cannot take the sudden extra strain the coated material may tear completely across its width, and such a happening in a drying tower is in the nature of a major catastrophe.

A rigid non-flexible selvedge, of course, concentrates upon itself practically the whole of the strain imposed on the coated cloth, and it may be strong enough to take it. The central portions of the body of the cloth, however, are thus substantially relieved of any strain, and since there is no force to hold them taut they belly and sag because of the combined weight of the cloth and the applied varnish. In other words the conditions are such that the central portions of the cloth expand lengthwise to a much greater degree than the selvedges. Moreover, since the cloths normally pass over rollers in towers, with constant peripheral speed along their entire widths, the selvedges also move over them at this speed; but with inelastic selvedges there is, in effect, a greater length of cloth to pass over in the centre of the width of the material than at the edges. It cannot move at a speed greater than that of the selvedges, and consequently distortions of the cloth occur and exaggerated strains are set up, which result in severe creasing and other troubles.

Broken Ends and Picks. Broken ends result from fractures of the warp threads, which have not been pieced up again. They cause long thin lines down a piece of fabric, because each broken end means that a warp thread is missing.

Broken picks, similarly, result from fractures of the weft

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threads, but in this instance lines are left widthways across the fabric.

It is sometimes possible to bridge these open lines with a film of impregnating varnish, but it is unwise to rely upon this.

Slubs. The excessively thick sections of cloth due to slubs, are a definite disadvantage because they cause irregularities in thickness, a defect which is transmitted to the impregnated material.

Floats. Floats and other stray pieces of yarn should be removed from cloth before impregnation; floats by cutting off down to the level of the fabric surface and other stray threads by gentle brushing. Abnormal protrusions of any kind from the surface of the cloth, or stray pieces of yarn, all tend to cause abnormal accumulations of varnish. These, in their turn, not only give rise to uneven film thickness, but to drying troubles also. Excessive accumulations of impregnating varnish do not always dry completely throughout their entire thickness, and incompletely dried impregnant is a serious menace.

Neps. The remarks above apply equally to neps, for they also attract abnormal accumulations of varnish. Furthermore, neps cause irregular varnish absorption, which lead to unsatisfactory electrical properties and other defects. Cloth should therefore be as free from neps as possible.

Excessive Size. Sizing of yarn is necessary for the weaving process, but its presence in the finished cloth may be a serious disadvantage. Agents may be introduced in the size which stimulate mildew development, and even chemical degradation of the yarns. Moreover, yarns heavily impregnated with size will prevent proper penetration of varnish. Size is also hygroscopic, a property which should be avoided at all costs in an electrical insulator.

Some sizes or lubricants have an inhibiting effect on the normal drying of impregnating varnishes, and this is another factor which must be given due consideration.

Size is normally substantially removed by scouring, but this is a process which is likely to be very unsatisfactorily done. A careful watch, therefore, should be kept on the size content of cloth and the presence of more than 1 per cent. should be regarded with suspicion.

Certain calendered cotton cloths used as the basis for insulating cloths are heavily loaded with starch or other sizing material. A discussion on the advisability of this is included in Chapter VIII.

Strength. A raw cloth before impregnation should be tested for strength, and this is usually accomplished by taking tensile strength measurements both of warp and weft threads. It must not be assumed that warp and weft yarns are equally strong; firstly because they may be of different counts, and secondly because the warp only may be sized, and the presence of size, as explained already, may be instrumental in inducing direct chemical degradation, or degradation as the result of fungus growth. Cloth may be quite strong initially, but may deteriorate under poor storage conditions. Heavily weighted silk, for example, may become quite tender, due to the combined action of the mineral matter present, sunlight, and atmospheric influences.

Cloths which have been "gassed," singed, or fired, may be weakened in the process if the cloth is left in contact with the source of heat too long. Weakness will be discovered if the yarn is visibly scorched or carbonised.

Tensile strength figures are really a measure of the resistance of the fabric to rupture as the result of a direct pull, *i.e.*, of a true tensile load. It is, however, rare in practice that failures occur from this treatment. Failures are more frequent from a tear, and tests are conducted therefore for tearing strength in both warp and weft directions.

Presence of Inorganic Salts. Cloths containing more than traces of inorganic salts, such as chlorides or sulphates, are very liable to lose their strength during subsequent processing, particularly if this processing involves heat treatment. Since the drying of impregnating varnishes on cloths is brought about, almost without exception, by the application of heat, the best conditions are present to promote the attack of the cloth by the above salts. All cloths, therefore, should be carefully extracted with hot water and the possible existence of chlorides or sulphates checked.

Traces of compounds of copper and certain other metals, in contact with oleo-resinous impregnants, have been shown to cause premature loss of strength on storage, and fabric containing more than the merest trace of copper, in particular, should be rejected. The deterioration caused by metals is, according to Monaghan (13), assisted by the presence of air and moisture, and a complete list of such metals, in addition to copper, includes tin, brass, lead, iron, cadmium and aluminium. Sulphur, although not a metal, has a similar disintegrating effect.

COTTON

Chemical Properties. Cotton is essentially a natural vegetable product and comprises in the main of cellulose (approximately 80–90 per cent.). Cellulose is made up of an arrangement of glucose units, each unit of glucose corresponding with the formula, $C_6H_{10}O_5$.

Cellulose is not so inert chemically as its physical appearance might suggest, and it is its chemical instability, coupled with its hollow construction, which are the main reasons for certain defects of varnished cloths.

Under ordinary conditions water has no serious degrading effect on cotton, but at elevated temperatures ($140^{\circ}C.$) and under pressure, cotton disintegrates and becomes tender. An accelerated test suggested to determine the stability of an impregnating varnish on cotton to storage under hot, moist conditions, consists in sealing the treated cloth with a little water in a glass tube and heating the whole for several hours. Under these very severe test conditions the cotton deteriorates and becomes tender as the result of two influences: chiefly because of attack by the products of degradation of the varnish film, but to an appreciable extent also by the effect of steam under pressure on cotton itself.

Cotton is completely decomposed by strong hydrochloric acid, and also by hot strong nitric acid.

Cold concentrated nitric acid converts cotton into dinitro cellulose.

Sulphuric acid attacks cotton in proportion to its concentration and the prevailing temperature.

Concentrated phosphoric acid also has a pronounced tendering effect.

When acids react with the cellulose of cotton, hydro-cellulose is formed.

Organic acids generally, such as oxalic, tartaric, formic and acetic acids, under mild conditions, do not attack cotton to any serious degree.

Boiling caustic soda turns some cotton cloths a pale straw colour. When cellulose is treated with caustic soda of the correct concentration, in the ratio of two parts of cellulose to one part of caustic soda, an alkali-cellulose compound is formed, and this is the primary reaction used in the conversion of cellulose into viscose silk.

Cellulose and cotton readily dissolve or disperse in ammoniacal solutions of copper oxide.

Cellulose can be converted to the nitrate ester by the action of mixed sulphuric and nitric acids, in other words, by the action of the usual acids used in organic nitrations.

Under suitable conditions, in the presence of catalysts, cellulose can be acetylated by means of acetic anhydride. Cellulose formates, nitro-acetates, benzoates, and butyrates have also been prepared.

Cotton is often bleached, but all bleaching agents tend to oxydise the cellulose to form a product known as oxycellulose. Great care, therefore, must be exercised in the control of the bleaching process to avoid unnecessarily prolonged contact with the reagents, for oxycellulose is considerably weaker mechanically than ordinary cellulose. In the processing of cotton, also, great care is taken to avoid contact with oxygen of the air. Oxydising agents, such as atmospheric oxygen in the presence of alkalis or moisture, chlorine, calcium hypochlorite, chloric, chromic and nitric acids, potassium permanganate, and hydrogen peroxide, react with cellulose to convert it into oxycellulose, with consequent tendering. Some workers consider that it is the formation of oxycellulose, in the presence of drying oils or their oxidation and degradation products, which causes the tendering of varnished cloths. The authors consider that there is considerable evidence to show that tendering is the result of a chemical attack on the cellulose, but whether the resultant product from this reaction is always oxycellulose or not is not so clear.

The presence of oxycellulose in cotton is detected by its greater affinity for methylene blue and basic dyes, and its lesser affinity for direct dyes. Oxy- or hydro-cellulose may be detected if the suspected cotton is dyed with methylene blue and then boiled with water. The dye washes out from pure cotton, but is permanent in parts of the cloth where oxy- or hydro-cellulose is present. Further information on the detection of oxy- and hydro-cellulose in cotton is given in Chapter IX.

Ethers have also been produced on the commercial scale from cellulose, and these include the methyl, ethyl and benzyl celluloses.

Sources and Types of Cotton. The cotton plant is widely distributed throughout the world and is grown in America, Egypt, India, Brazil, Peru, West and parts of East Africa, the West Indies, Russia, Persia, Sudan, Mexico, Japan, the East Indies and China. The chief difference between the various types of cotton from these different sources is the length of the staples.

American cotton, for example, is known as medium or short

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staple cotton, the individual fibres being up to 1 inch long. The Punjab produces a similar type of American cotton. Egyptian cotton, on the other hand, is peculiar by reason of its exceptionally long staple which varies from $1\frac{1}{4}$ to $1\frac{3}{4}$ inch in length. Sea Island cotton, which is also of American origin, is, like Egyptian cotton, a long staple variety.

Table 1
Length and Diameter of Cotton Fibres (1)

Type	Average Length (ins.)	Average Diam. (ins.)
1. Indian	0·6-1·0	0·00084
2. American Upland	0·8-1·1	0·00077
3. Peruvian (smooth)	0·9-1·1	0·00077
4. Brazilian	1·1-1·4	0·00080
5. Peruvian (rough)	1·2-1·5	0·00078
6. Egyptian	1·3-1·6	0·00068
7. Sea Island	1·6-2·2	0·00064

Further details on the sources, grades of cotton, amounts of crop and length of staple are given in a comprehensive table by Peake (2).

General Characteristics of Cotton Fibres. The characteristics of cotton vary according to the place and method of cultivation, and the following remarks apply only in a very general sense.

Table 2

Type	Characteristics
Sea Island	Fine, long, lustrous and silky. Creamy colour.
Egyptian	Fine, long and strong. Brownish colour.
Peruvian (rough)	Very harsh fibre.
Indian	Coarse and short.
American Upland	Similar to Indian, but somewhat longer and generally of better quality.
Peruvian (smooth)	Very similar to American Upland.
Brazilian	Harsh and wiry, but of good length. Fairly strong.

Construction of the Cotton Fibre. Perhaps the first thing to remember about cotton is its existence as a collection of short fibres which are only about 1 to 2 inches long. This difference is fundamental, because natural silk and artificially produced fila-

ments are continuous for many tens of yards, in fact the length of synthetic filaments is practically limitless.

Before cotton fibres reach maturity they consist of hollow cylindrical tubes, but in the process of ripening the cylindrical shape gives place to a hollow irregularly flattened ribbon, and the fibres take on a twist. The amount of twist varies, and is roughly inversely proportional to the diameter of the fibre. Cotton fibres are also unique by comparison with synthetic fibres in that whereas the former are hollow, the latter are solid in section. Photomicrograph below clearly shows the tubular structure of cotton fibre and also its natural twist. The hollowness of cotton



FIG. 14. Cotton fibre showing hollow construction. (Polarised light. Magn. 360.)

fibres is a great disadvantage from an electrical point of view, for it is extremely doubtful that the space inside the fibres is ever effectively filled with impregnating varnish. This leads to the conclusion that varnished cotton cloth, especially if well starched, consists of little more than a sandwich of air between outer layers of dried varnish. Occluded air subjected to high-frequency voltages is a possible cause of electrical breakdown.

This statement is not meant to imply that varnished cloth built up on a starched calendered cotton textile support, is valueless for electrical insulation, but it is made deliberately to provoke thought upon the subject. Is the starched calendered cotton base the best support which can be used ?

The photomicrograph of Fig. 41, in Chapter VII, shows the flattened hollow cotton fibres, and it was obtained by cutting a section through a piece of varnished cloth.

Immature or "dead" cotton fibres possess very little, if any, twist, and as a consequence have unsatisfactory strength. They should be avoided in the manufacture of cloth for two reasons : for their reduced strength, and for their reduced absorption properties. The fibres of cotton grown under poor conditions may also contain a reduced number of helical twists.

The two ends of the cotton fibre differ. That drawn from the seed is rough and open ; the other end is pointed and closed.

The strength of individual fibres varies considerably. From 46 to 212 grains are necessary to cause a break.

Composition of Cotton Fibre. The composition of cotton fibre varies appreciably according to its origin, but the following figures supplied by the United States Department of Agriculture, Bulletin 33, indicate its complexity.

Table 3
Composition of Cotton Fibres

	Per cent.
Cellulose	83·7
Water	7·0
Protein	1·5
Mineral matter . .	1·65
Cotton wax and oil . .	0·6

Other sources give a higher cellulose content of about 90 per cent. In addition, cotton fibres normally contain about 6–8 per cent. moisture.

The mineral matter in cotton consists of the chlorides, phosphates, and sulphates of potassium, sodium, magnesium, and calcium. Traces of iron and aluminium may be present also. Sometimes minute traces of other metallic compounds, such as those of copper, can be detected.

It is possible to remove the cotton wax, and oil, from the cotton by boiling under pressure with dilute alkali.

Although size does not, of course, enter into the composition of natural cotton fibres, it is quite likely to be present in woven cloth to some extent. Sizes may contain the following constituents : flour from wheat, rice and maize ; sago and tapioca ; starches from these flours and also from potato and arrowroot. In addition, a number of water-soluble gums, and similar materials are used, including dextrine, Iceland moss, casein and gelatine.

Other agents are also used which act as lubricants, and they are introduced to give the yarn elasticity and flexibility. They include substances of an oily nature, such as the vegetable oils—castor, palm, olive and coconut oils ; tallow ; waxes, such as spermaceti, beeswax, and Japan wax ; and soap elaine and turkey red oils. Tallow is probably the most popular lubricant, and it is notoriously difficult to saponify it away by a lime or caustic boil.

Sometimes further softening agents are introduced like glycerine and glucose, or certain inorganic salts like magnesium chloride. Zinc chloride is also sometimes incorporated because it prevents the formation of mildew.

The presence of traces of the chlorides of zinc, calcium or magnesium in cotton cloth which is to be singed, is dangerous, for on heating in the presence of moisture, these salts decompose and hydrochloric acid is liberated. This tenders the cotton.

The exact compositions of most commercial sizes are closely guarded secrets, but the substances mentioned above are known to be popular constituents. Monaghan (18) gives two examples of representative sizes. Water, 100 gallons ; corn starch, 125 lbs. ; gum, 25 lbs. ; and tallow, 12 lbs., are boiled together for about an hour. For a size based on potato starch, water 100 gallons ; potato starch, 110 lbs. ; gum, 20 lbs. ; and tallow, 12 lbs., are brought to the boil and held at the boil for ten minutes only.

One or more of a formidable array of antiseptics are also likely to be used in cloth manufacture, and a comprehensive list includes oxalic, boric and salicylic acids ; the chlorides of zinc and sodium ; the sulphates of zinc and aluminium ; sodium borate, carbolic acid and creosote, and special antiseptics of undisclosed composition.

The presence of some of these materials in cotton cloth has an adverse effect on the normal drying process of impregnating varnishes. Boric acid has been found to cause heating up and tendering.

The Manufacture of Cotton Cloth. The manufacture of cotton cloth from the natural fibre involves many processes, and some knowledge of these is an asset both to the formulator of the impregnating varnish, and to the proofer or producer of the finished varnished cloth.

Briefly these processes may be enumerated and described as follows :—

1. Ginning.
2. Mixing and opening.
3. Spinning.
4. Sizing.
5. Weaving.
6. Gassing.
7. Scouring.
8. Bleaching.
9. Calendering.

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Ginning. Cotton fibres still adhering to the seeds is known as seed cotton. In the process of ginning the fibres are torn from the seeds, a procedure which is carried out on or near the cotton fields. After ginning, the cotton is compressed into bales for export, and it contains small amounts of dirt, seed, and broken and torn fibres.

Mixing and Opening. The bales then pass to a breaker or mixing machine. The cotton is broken down and some of the heavier dirt is removed by the force of gravity. A certain amount of mixing of different cottons may also take place in the bale breaker.

After the bale breaker there is a further mixing of various cottons, and the mixtures are passed through a succession of machines like the Hopper feeder, the Scutcher and the Carding Engine, which have the effect of opening out the cotton and making it cleaner.

For super quality yarns the cotton is combed, and short fibres and more impurities are removed in the process.

Spinning. The cotton, now a soft fluffy mass, is then converted into long continuous sausages of material, which are gradually reduced in diameter and given a certain amount of twist. These are then finally spun into yarn, and are spun soft or hard according to the type of yarn required.

Sizing. Yarn as received from the spinner is quite unsuitable for weaving. It is rough and hairy because of the hundreds of stray ends of fibres which protrude to varying lengths beyond the surface of the yarn. The hairy yarn is passed through size solutions and then through a heated chamber. When it emerges most of the volatile water has been expelled, and the loose hairs are laid flat, along and close to the surface of the yarn; the yarn is ready for weaving into cloth.

In the sizing process the main object is to introduce the size thoroughly into the threads and not merely to form an exterior envelope. In fact the cotton trade describes as the best size the one with the greatest penetrating power. From an electrical point of view, however, the less size used the better.

Sizing materials generally have very poor insulating properties, and this, in the main, is because of their hygroscopicity. Even with good electrical insulators a slight absorption of water has been shown to cause a very marked drop in dielectric strength. Sizes, by contrast, have high water absorptions, and their dielectric strengths under moist conditions are almost negligible.

Dry sizes too are rarely flexible—they fracture easily on bending. Toughness and elasticity are of paramount importance in a flexible insulator.

It will be argued, with some truth, by the cloth manufacturers, that whatever size is used to facilitate weaving, is removed subsequently. This contention is not, however, strictly correct, for traces of size are nearly always present in the cloth. This is especially the case when every effort has been made previously to ensure perfect penetration of the size.

Weaving. The sized thread is next woven into cloth, and it is during weaving that many faults may occur. Cloth as it leaves the loom in its unfinished condition is said to be “in the loom state.”

Gassing, Scouring and Bleaching. After weaving, the cloth contains large amounts of impurities, which include all the constituents of the size, and possibly oil from machinery. The total of the impurities is often about 25 per cent. of the total weight of the cloth.

If the cloth is to be bleached satisfactorily, all these impurities must be removed, but before this is done the cloth is subjected to a gassing process.

The gassing process is described also as firing or singeing. The gassing, firing or singeing may take place at one or two stages during the manufacture of the cloth. The yarn itself may be passed rapidly through a gas flame which is adjusted to burn off all protruding hairs and to leave the yarn in a smooth and round condition. Alternatively the woven cloth may be passed rapidly over special gas burners, red hot metal plates, or electric grilles. The operating temperatures are about $1,100^{\circ}\text{C}$. This operation is a very delicate and dangerous one, for the speed of the cloth is adjusted for a given flame or plate temperature, so that all protruding hairs are burnt away without singeing the body of the cloth; overheating of the cloth means a considerable reduction in strength. Sometimes the singeing process is conducted in complete darkness so that as the treated cloth emerges, red hot sparks can be readily detected. Other singeing processes involve quenching the heated cloth in water to avoid the chance of a serious conflagration.

The gas-burner method, in which coal or other gas, reinforced by a strong air blast, is used as the burning medium, is claimed by many to be much more satisfactory than the hot-plate method. The former method is said to be effective in removing not only

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the hairs from the face side of the cloth, but from within the interstices of the cloth also. The force of the hot blast of flame is adjusted to detach, theoretically, all the intervening hairs, and to leave the yarns quite clean in every direction. Both face and back sides of cloth are so treated.

Gassing or singeing of the piece is more satisfactory than simple singeing of the individual yarns, for although the yarn may have been clean before weaving, the actual operation of weaving is very likely to cause more fresh hairs to detach themselves.

After the gassing the fabric is soaked in water to soften and loosen the size constituents and other water-soluble materials. It is then washed and treated successively with lime, with soda ash to saponify away vegetable and other fatty acids, with water, and then with a bleaching agent. The commonest bleaching agent is chloride of lime. Traces of this chemical are removed by further washing, and acid treatment. Finally, a washing with water is given to remove acid.

Sometimes, the fabric after gassing, is treated with malt, and left steeped for twelve hours or so in warm water. During this time a fermentation of the sizes occurs and this facilitates their subsequent removal.

Cotton cloth for the production of varnished cloth, is used both in the bleached and in the unbleached or grey conditions. Actually there seems to be very little advantage to be gained, if any, by using bleached cotton cloth for impregnation, apart from its clean appearance in the raw state. Whenever bleaching agents are used there is always the danger that chemical action may induce weakening of the cotton, so that if this possibility can be avoided it seems wise to do so. Certain highly reputable manufacturers of insulating fabric always use unbleached cotton.

For the production of good quality varnished cloths, singed, cotton cloth is unsatisfactory—it is still far too rough. It is made more suitable for treatment by subjecting the cloth to a starching and calendering process, which consists essentially in passing the starched cloth between heavy hot rollers which have the effect of laying down the hairs and flattening out the threads, tape-fashion. If the cloth is heavily starched, which is often the case, the calendering process causes the hairs and other protrusions to be firmly embedded and cemented in place. Some insulating cotton cloths are so highly starched that the resultant product has the appearance of a continuous glossy sheet of white starch. Cotton

cloth used for some types of insulating cloth, including that converted into adhesive tape, is not calendered.

The starch or other size may be applied by several different

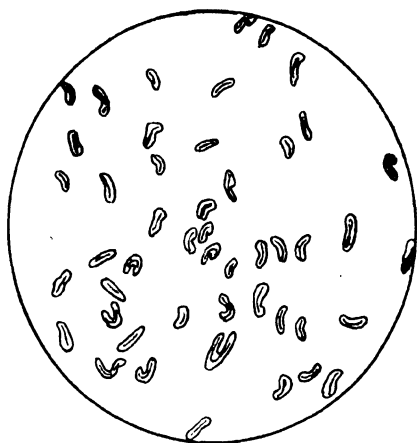


FIG. 15. Cotton. (Magn. 75.)

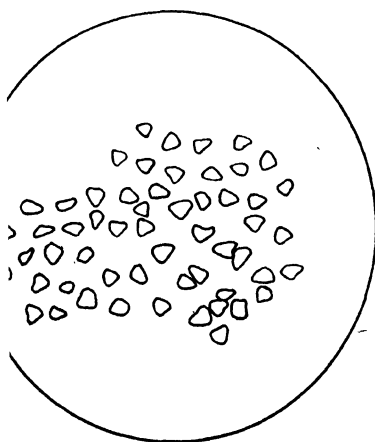


FIG. Natural silk. (Magn. 170.)

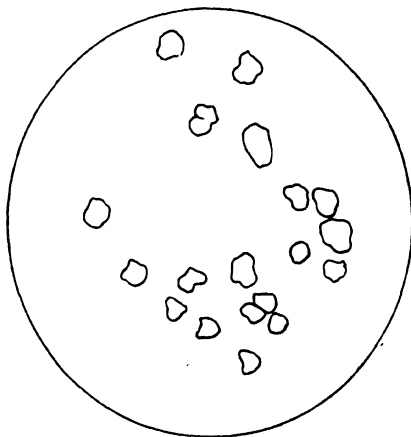


FIG. 17. Cuprammonium silk.
(Magn. 190.)

processes, including immersion of the fabric in an aqueous dispersion or solution of the starch or size, followed by passing through rolls to force the starch into the fabric; passing the fabric between two rolls rotating at different peripheral speeds, so that

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the starch is ground into the fabric as the result of a slip or friction action; spraying of the starch solution on to the fabric, or applying it by means of a printing machine.

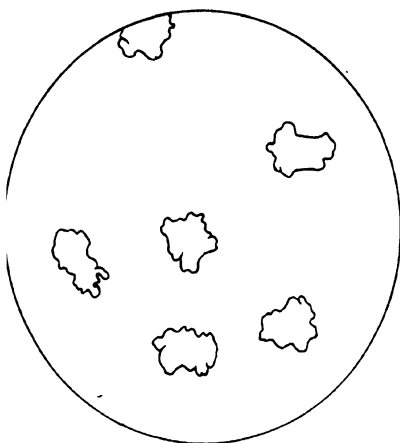


FIG. 18

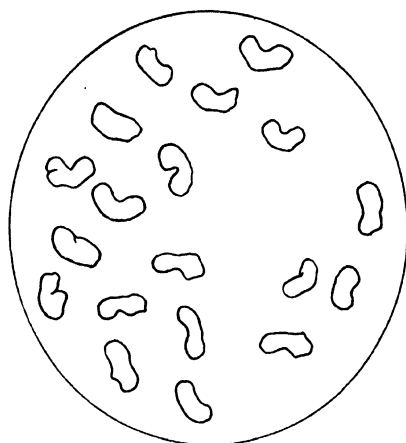


FIG. 19

Two different types of viscose. (Magn. 190.)

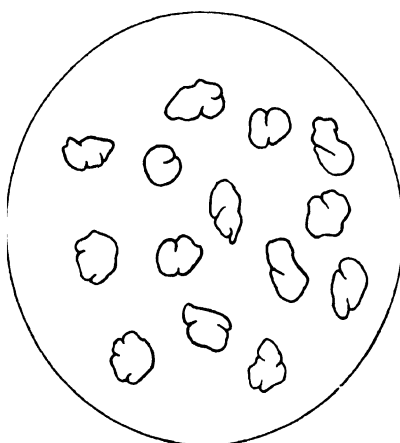


FIG. 20. (Magn. 190.)

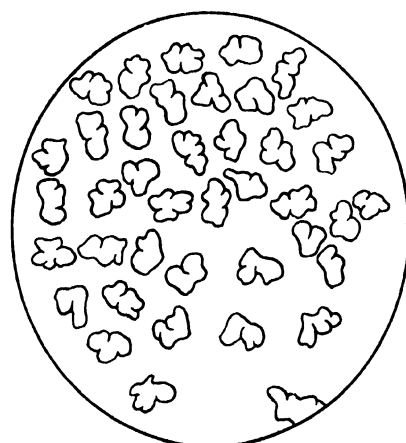


FIG. 21. (Magn. 225.)

Two different types of cellulose acetate.

The starched fabric is dried by festooning, drying on tenters, or by passing it over steam-heated cylinders. It is then moistened slightly and passed between heavy, heated rolls, the effect

produced being dependent, among other things, upon the pressure and temperature of the rolls.

Starched and calendered cloth is much less flexible than the untreated material, but it possesses the property of lying permanently flat and free from wrinkles.

It does not present such a smooth surface as fabrics made from continuous filament materials such as the artificial silks. Occasional fibres still protrude from the surface and this is illustrated by the photomicrographs on p. 17.

These fibres may be long enough to extend beyond the boundary surface of cotton cloth treated with as many as four coats of impregnating varnish. If it so transpires that these fibres are not thoroughly saturated with varnish, they may act as wicks, and conduct moisture well into the varnished cloth. It is not inconceivable that the effective thickness of cloth from an electrical insulating viewpoint is reduced by at least half. The photomicrograph of Fig. 40 shows how many cotton fibres from a tuft in the fabric have protruded a considerable distance beyond the surface of the varnished cloth.

Mercerisation. This is a process sometimes applied to cotton thread or woven cloth to give them a silky lustre, to improve absorption of dyes, and to increase tensile strength. The cotton is steeped in an alkaline solution either under tension or otherwise. If it is not kept under tension shrinkage occurs, but ultimately it is stretched again to its original length whilst still in contact with the alkali.

The actual structure of the cotton fibres is changed from the flat form to hollow cylinders which are more nearly spherical in section.

NATURAL SILK

Chemical Properties. Silk, as distinct from cotton, is an animal and not a vegetable product.

It dissolves in hot caustic alkalis—both in potassium and sodium hydroxides. It is also readily dissolved in mineral acids, including sulphuric, nitric and hydrochloric acids. Basic zinc chloride solution, and ammoniacal cupric or nickel oxide solutions are other satisfactory solvents.

Tussah or tussah silk is not dissolved by caustic alkalis.

Silk is rather hygroscopic, absorbing up to 15 per cent. of moisture; most of this can, however, be expelled on heating to temperatures in excess of 110° C.

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Sources and Types of Silk. The mulberry feeding silkworm produces "true silk," other silkworms produce "wild silk." The mulberry silkworm is indigenous to China, but is found also in many other parts of the world where the mulberry tree grows. The wild silkworm thrives in Japan; China; parts of India, including Assam and Mysore; and in Africa. In addition the tussah worm breeds in India and China.

Construction of Silk Filaments. Silk filaments are exudations from silkworms. The worm itself possesses two glands from which the viscous "silk stream" emerges into two ducts; from these ducts it is conveyed through a common orifice into the air. Simultaneously the two separate streams are coated with a liquid adhesive, whose function is to cement the two components together into one simple filament (the bave). Each of the parallel strands of the bave is known as a brin.

When the cemented strands come into contact with the air they coagulate to form a tough continuous filament. The length of filament from a single cocoon may be from 300 to 500 yards long. Its diameter varies according to the source, wild silk possessing a greater diameter than true mulberry silk.

Table 4
Diameters of Silk Filaments

Type of Silk	Diameter Limits for the Double Strand (bave) in inches
Mulberry silk	0.0008-0.0010
Wild silk	0.0016-0.0026

It is apparent, therefore, that a silk filament has a larger diameter than a cotton filament, especially in the case of wild silk. The diameter of the filament is not strictly constant throughout the entire length, for the worm becomes progressively weaker as it spins and the thinnest part is exuded last.

Natural silk is spun by the worm in the form of a solid cylinder, and has no cell structure whatsoever; a faint line seems to run down the centre of the cylinder, but this is caused by the junction of the two constituent filaments. The more effectively the separate filaments are joined together, the less obvious the line, and the better the quality of the silk. The photomicrograph on p. 35 shows a typical solid natural silk filament.

Composition of Silk Filament. A single silk filament really consists of two concentric cylinders; the solid or inner cylinder is composed of a substance called fibroin, and the outer cylinder

consists of sericin. Both substances are proteins, but they differ widely in properties. Sericin or silk-gum is easily soluble in hot water, but fibroin is quite insoluble, and it needs treatment by concentrated alkalis or acids to effect a solution.



FIG. 22. Natural silk filament showing typical solid construction. (Polarised light. Magn. 360.)

The composition of raw silk has been given as :—

	Per cent.
Fibroin	70-75
Sericin	20-25
Mineral matter	1-5
Wax	1

The fibroin of different silks has substantially the same composition irrespective of the source of the silk, and this is demonstrated by analyses of the products of hydrolysis obtained from them. The products of hydrolysis consist chiefly of glycine, alanine, and tyrosine, which together constitute about 50-70 per cent. of the whole. In addition, smaller amounts, or traces of the following have been isolated ; leucine, serine, phenylalanine, proline, and aspartic and glutamic acids. The products of hydrolysis of the sericin are similar to those from the fibroin, but they are more nearly equally distributed in amount.

The Manufacture of Silk Fabric. The silk is removed from the cocoon where it was spun by the worm, by placing the cocoons in almost boiling water. The fibre is then drawn off as a thread. About half the silk is capable of being unwound, the remainder is combed or carded and subsequently spun. A number of silk fibres are drawn off simultaneously—sometimes as many as twelve—and a single thread of uniform thickness is produced from them.

Different forms of weaving thread are produced from the natural filament, and they are known as singles, tram or organzine. Singles are made by twisting one of the original filaments on itself, tram is made by twisting two or more threads together, and often

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constitutes the weft thread. Organzine comprises two or more singles threads, but they are twisted together in a reverse direction to the twist on the singles thread.

Silk is usually degummed before conversion into fabric, a process which consists essentially in subjecting the silk to the action of a soap solution almost at the boiling point. This treatment has the effect of dissolving away the sericin, and the two strands (brins) tend to separate.

The silk, therefore, used in textile manufacture, consists of practically pure fibroin. The boiling or degumming of silk improves its lustre and flexibility—the raw silk losing its wiriness and stiffness.

Some silk fabrics are manufactured in the “ gum state ” because weaving of raw silk is easier than with boiled silk, the former being substantially stronger. During this boiling process about 25 per cent. of the weight of the woven fabric is lost. Before the weaving of Japanese silk the warp thread is sized with a preparation known as funore.

Table 5

Habutai—A Table of Weaving Particulars

(from “ Oilsilk,” by permission of F. Warner, Esq.)

		No of Threads per $\frac{1}{2}$ in (5 Fun)				
		Warp	Weft		Margin of Weight	
Single warp, single weft.	Up to $2\frac{1}{2}$ momme	70	45	momme		
	Up to $3\frac{1}{2}$ momme	75	50		Above standard	Below standard
	Up to $3\frac{1}{2}$ momme	75	52	$2\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
	„ „ $4\frac{1}{2}$ „	75	55	$2\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$
	„ „ $5\frac{1}{2}$ „	75	60	3	$\frac{1}{2}$	$\frac{1}{2}$
Single warp, double weft.	Over $5\frac{1}{2}$ „	75	65	$3\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
	Up to $5\frac{1}{2}$ momme	75	55	4	$\frac{1}{2}$	$\frac{1}{2}$
	„ „ $6\frac{1}{2}$ „	75	60	$4\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
	Over $6\frac{1}{2}$ „	75	65	5	$\frac{1}{2}$	$\frac{1}{2}$
Double warp, single weft.	Up to 6 momme	75	60	$5\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
	Over 6 „	75	65	6	$\frac{1}{2}$	$\frac{1}{2}$
Double warp, double weft.	Up to $6\frac{1}{2}$ momme	75	50	—	—	—
	Over $6\frac{1}{2}$ „	75	55	—	—	—

Up to the outbreak of the recent war the silk used for the production of varnished silks came chiefly from Japan. The silk fabric used is known as Habutai, and comes on to the market in various weights (momme). The lightest silk fabric is produced at Kawamata ($2\frac{1}{2}$ –4 momme). Kaga produces 4–5 $\frac{1}{2}$ momme, Echizin 5 $\frac{1}{2}$ momme and upwards, and Takefu and Sabæ 6–7 momme silk.

Low grades of silk are used for Habutai fabric, and this accounts for the prevalence of streaks and bars in it.

The table shown on p. 36 gives details of weaving particulars of Habutai (21).

According to Warner (*loc. cit.*) silk woven in Great Britain is much stronger than the equivalent Japanese product. Mixed fabrics containing both natural and artificial silk have been woven recently in Great Britain, especially for varnishing.

FABRICS FROM MINERAL FILAMENTS

GLASS

Glass fabrics have only recently been introduced into the textile world, and while there appear to be many problems of production—formation of fibre, spinning of the yarn and weaving—to be overcome, glass fabrics suitable for certain purposes have been produced on the commercial scale.

Chemical Properties. Glass filaments have attracted considerable interest in the electrical world by reason of their extreme chemical inertness, and it is not to be wondered at, therefore, that glass-woven fabrics, often referred to as glass silks, have been used as supports in varnished cloths for use at very high operating temperatures.

Disintegration of organic filaments, on heating to temperatures in excess of 110° C. for many hours, is a disadvantage which has been bemoaned for a long time. Under these conditions the formulator of the impregnating varnish had a relatively easy task, for he had only to produce a varnish with heat-resisting properties equal to or slightly superior to those of the supporting textile. The introduction of glass fabric has turned the tables with a vengeance. The problem now is to produce an impregnating varnish with a heat resistance comparable to that of glass. This is no easy matter.

Furthermore, designers are faced with the difficult task of

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designing electrical plant to withstand temperatures substantially in excess of the Class A and B operating temperatures. Plants operating at temperatures of 150°C . seem to be an accomplished fact, and satisfactory reports have been received also of experimental motors operating at 230°C ., but oxidation of conductors and other problems of design occur at these high temperatures, and they are not easy to solve.

Stirrat (4) provides a good example of the exploitation of the heat-resisting properties of glass filament insulators in a fractional H.P. motor for a washing machine. Its normally insulated starting coil tended to burn out under stall conditions in about five seconds. When glass filament insulated wire was substituted in the starting coil, it stood up for twenty minutes under stall conditions before failing, and it was possible to dispense with the cut-out.

Moses (6) has conducted experiments on glass insulated magnet coils which were operated at 575°C . ($1,067^{\circ}\text{F}$.). The impregnant was completely destroyed, but some of the coils operated satisfactorily, nevertheless, for several hours.

Glass insulated wire is claimed not to burn out below 900°F .

The breaking strength of glass staple-filament tapes (0.01×1.0 inch), subjected to various temperature conditions, has been determined by Atkinson (5).

Table 6
The Effect of Heat on the Breaking Strength of Glass Tapes
Average Breaking Strength (lbs.)

Original	$400^{\circ}\text{F.}/30$ mins.	$400^{\circ}\text{F.}/30$ mins. each day for 10 days	$500^{\circ}\text{F.}/30$ mins.	$500^{\circ}\text{F.}/20$ mins. each day for 10 days
210	219	190	194	146

These results indicate that even after ten periods of heating at 500°F . for thirty minutes each, the tapes retained about 80 per cent. of their original strength.

The same worker has made comparisons of the heat resistance of glass, cotton, and asbestos filaments.

The figures given in the following table are all for tapes of the same dimensions, *i.e.*, 0.01×1.0 inch.

Table 7

The Effect of Heat on the Breaking Strengths of Glass, Cotton, and Asbestos Filaments

Material	Temperature (° F.)	Breaking Strength (lbs.)
<i>Continuous fibre glass</i>	0	490
	200	495
	400	500
	600	450
<i>Staple-fibre glass</i>	0	200
	200	205
	400	203
	600	165
<i>Cotton</i>	0	85
	200	85
	400	60
	500	0
<i>Asbestos</i>	0	20
	200	20
	400	18
	600	15

Glass is obviously much stronger than cotton and asbestos, initially, and at elevated temperatures.

Anderegg (7) confirms that the heating of glass filaments at 570° F. for forty-eight hours produces little, if any, change in strength.

Retention of strength at high temperatures is especially important when tapes are used for binding coils or holding other forms of insulation firmly in place. The high tensile strength of glass permits the use of thinner tapes, with a corresponding improvement in space factor.

Another property of glass associated with its chemical constitution is its non-inflammability. This means that with special impregnating varnishes fire-resisting insulating cloths may be produced. Other filaments used in textiles, with the exception of asbestos, are combustible.

Not only is glass resistant to disintegration by heat, but it is very resistant also to a wide range of chemical compounds.

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Table 8 (8) shows the effect on the tensile strength of both warp and weft threads of glass cloth, after its immersion in various chemical solutions.

Table 8

The Effect of Chemicals on the Tensile Strength of Glass Cloth

Chemical Solutions	Tensile Strengths (lbs.)		
	Warp	Weft	
Untreated	340	219	60 hours' immersion, including 12 hours at 80–100° C.
10 per cent. H_2SO_4	195	226	
50 per cent. H_2SO_4	227	204	
98 per cent. H_2SO_4	175	150	
H_3PO_4	76	88	
35 per cent. HCl	281	213	
30 per cent. HNO_3	212	178	10 hours' immersion at 85–95° C.
20 per cent. ZnSO_4	308	303	
20 per cent. ZnCl_2	328	240	
CH_3COOH glacial	230	243	
$\text{C}_6\text{H}_5\text{OH}$ pure	241	198	

From the results as given in Table 8, therefore, except for phosphoric and concentrated sulphuric acids, the retention of the tensile strength of glass fabric after exposure to corrosive chemicals is good. The fabric used for the tests in the table was a plain weave using No. 14 yarn, and weighing $1\frac{1}{2}$ oz. per square foot. This feature of glass fabric means that it can be used for the insulation of electric motors for chemical and other works where accidental splashes of certain acidic corrosive liquids are likely.

Anderegg, however, states that alkali glasses are apt to be attacked by alkalis, but seem resistant to acids. The tendency to attack by alkali is reduced by coating the filaments with alkali-resistant synthetic resins such as acrylic or methacrylic resins, or with chlorinated rubber. Alkali-free glasses resist alkalis better than acids.

Because of its inorganic nature and its general chemical inertness glass does not deteriorate on ageing. Loss of strength on ageing

is, however, noticed with cotton and artificial silks in particular, and it may become a very serious matter.

Some impregnating varnishes disintegrate seriously by the prolonged action of atmospheric heat, oxygen, or moisture, and give rise to a series of reactive degradation products. Glass is not susceptible to attacks of these products. Glass is also quite resistant to attack by mildew.

The water absorption of glass filament is very low by comparison with that of cotton, natural silk, etc., and it has been claimed that electric motors with glass filament insulation can be hosed down without suffering permanent damage. Glass itself may be classed as non-hygroscopic, and it retains only about one-twentieth of the moisture retained by cotton. Glass reaches a state of moisture equilibrium much more quickly than cotton, and this fact is of great importance in the drying out of components before impregnation.

At first sight glass fabric seems to be ideal for resistance to moisture absorption, but its intrinsic water resistance is modified by external factors. The glass surfaces of the individual filaments attract moisture to themselves where it is adsorbed. Sizes are also used during the manufacture of the fabric, and, of course, these have great affinity for water, which is, in fact, tenaciously held by them. The extent of the absorption of water by the size depends upon the amount of size present, which in turn is determined by the efficiency of the scouring process. Finally, as with all filaments which are held closely together in large numbers, there is the ever-present possibility of water being drawn into the fabric and trapped between the filaments by capillary attraction.

The moisture absorption may be modified also by capillarity between the filaments themselves and the surrounding impregnant which may not wet them completely. The wetting properties of glass alone, and of glass with lubricant or size, may cause difficulties during impregnation, and leave the filament surfaces incompletely coated. The spaces left are likely to cause water to be carried along by capillary action.

It will be seen, therefore, that non-hygroscopicity of the material of the filament itself is not the only factor to be considered in assessing the moisture resistance of a textile-varnish system.

Cotton differs from glass in that it absorbs water by a wick action. The comparative effect of water on various unimpregnated tapes is illustrated clearly in figures published by Atkinson (*loc. cit.*). The thickness of the cloth was measured before and after

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boiling for fifteen minutes, in water containing $\frac{1}{2}$ per cent. soap and $\frac{1}{3}$ per cent. soda ash, followed by drying at 225° F. for thirty minutes, and conditioning at room temperature for ninety-six hours.

Table 9

The Effect of Boiling Water on the Thickness of Glass, Cotton and Asbestos Tapes

Material	Thickness (inches)	
	Before Boiling	After Boiling
Continuous filament glass . . .	0.0168	0.0135
Staple filament glass	0.0162	0.0152
Cotton	0.0121	0.0156
Asbestos	0.0151	0.0201

An increase in thickness is observed with cotton and asbestos, but not with either of the two types of glass tape.

Composition of Glass Filament and the Effect of Constituents on its Properties. Glass is composed chiefly of silica, and this, because of certain defects and difficulty of manipulation, is modified by the addition of many other compounds. They include the alkalis—compounds of sodium and potassium; the oxides of calcium, barium, zinc, magnesium, and aluminium; and borax. Each of these has a special function and a careful balance of the ingredients is necessary.

One of the chief characteristics of glass for filaments is that it must possess a viscosity range which is suitable for drawing the glass into filaments.

For filaments which are to be converted into fabric for electrical purposes, the alkali metals, sodium and potassium, and other monovalent elements are eliminated.

Atkinson (5) has shown that the presence of alkali seriously reduces the insulation resistance of glass under humid conditions. After subjecting a low alkali glass to a constant relative humidity of 90 per cent. at 100° F. for seventy-two hours, its insulation resistance was only one-fortieth that of alkali-free glass, treated similarly. Atkinson explains this by stating that the alkali leaches to the surface and provides an ionizable salt there. Robertson (8) attributes the electrical failure of alkali glass to the fact that the free soda or potash present leach to the surface of the

filament, absorb moisture there, and break down the glass by attacking the silicates.

The strength of glass is altered considerably by the presence of impurities, but by careful control it is possible to increase the strength by their elimination, until it exceeds that of steel; even so, only some 3 per cent. of its atomic strength is utilised (7). Gas bubbles are one of the chief impurities.

Strengths of the order of 400,000 to 1,000,000 or more pounds per square inch for fine textile filaments are claimed. Silica yields filaments with tensile strengths considerably in excess of 1,000,000 lbs. per square inch. Strengths up to 3,500,000 lbs. per square inch have been reported.

Glass filaments exhibit practically no elongation under tension. The average percentage elongation at rupture of a large number of filaments gave a figure of 4.24 per cent. Organic filaments, on the contrary, have percentage elongations of the order of 20 per cent.

Other sources give the average stretch of glass filament, under specified conditions, as 1 or 2 per cent., by comparison with 5 per cent. for cotton and 15 per cent. for artificial silk. In spite of the discrepancy between the two sets of figures they both indicate that glass has a much smaller percentage elongation than that of organic filaments. The low stretch of glass is claimed as a big advantage, in that varnished cotton cloth when subjected to a stretching force in excess of the elastic limit of the varnish film, disintegrates the film and insulation is impaired. Whereas cotton and other fibres stretch appreciably, glass filaments do not, and hence there is much less chance of rupture of the film of varnish as the result of excessive stretching.

In dealing with the subject of the composition of glass filaments it is convenient also to discuss other substances which may be present in the glass woven cloth, and which have been used to facilitate filament formation, spinning or weaving.

Lubricating oil is actually sprayed on to or applied to filaments during their manufacture, whether they are of the staple or continuous types. It is essential to coat the filament with oil or some sort of size, for abrasion or vibration of the filaments against each other during textile manufacture causes "nicking" or actual "cutting through" of the filaments.

Judging from the smell of some of the glass woven fabrics examined, the glass seems to have been treated with a lubricant or size containing materials like stearine.

Poor abrasion resistance is one of the limitations of glass silk,

and the presence of a lubricant is essential to minimise the possibility of self-damage. When, however, the silk has been thoroughly impregnated with an insulating varnish, this has the effect of protecting the filaments from mutual abrasion, and varnished glass silks do not suffer from deterioration in use because of abrasive action.

Unfortunately the oil and/or size in raw glass silk militate against obtaining the best electrical properties in the varnished silk, for they interfere with penetration, and may inhibit the normal drying process of the varnish. If these troubles arise in practice, then the oil or size must be removed, and this is conveniently effected by degreasing, by immersion in or by refluxing with chlorinated hydrocarbons such as trichlorethylene.

The abrasion resistance of raw glass silk is stated to be similar to that of equivalent asbestos cloth, but markedly inferior to that of cotton. After impregnation, however, the glass silk is the strongest of the three materials.

Construction of Glass Filaments. Glass filaments are solid cylinders and they may vary considerably in length. They are of two types—staple and continuous. The former vary in length from 3 to 15 inches, but the latter are almost limitless. Filaments twelve miles or more long are common. Continuous filament is preferred for electrical purposes.

Staple filaments are made approximately 0.00025 inch diameter and continuous filaments are somewhat finer, being normally only 0.00020 inch diameter. Both the staple and the continuous glass filaments are much finer than either cotton or natural silk filaments; cotton fibres have approximately four times the diameter of glass filaments, and silk filaments have at least five times the diameter. It is the extreme fineness of the glass filaments that gives glass silk its valuable flexibility.

It is possible, if desired, to obtain glass silk thinner than 0.002 inch thick. For electrical insulation generally the very fine continuous filament is used for conversion into fine silks, and the thicker staple filament is used extensively for heavy cloths and tapes.

According to Robertson (*loc. cit.*) all weights of continuous yarn are made from the same basic thread; a thread consists of 102 filaments, each about 0.0002 inch diameter. The standard thread requires 90,000 yards to weigh 1 lb., which gives a count of 900.

The following table provides an approximate comparison of the counts of glass yarn with other systems of measurement.

Table 10

Comparison of Counts of Glass with the Systems of Measurement for Silk and Cotton. Robertson (22)

Nominal Yds. per lb.	Glass Fibre	Silk (Denier)	Cotton (840-yd. Hank)
90,000	1/900 *	50	106
45,000	2/1/900	100	58
22,500	4/1/900	200	27
22,500	2/2/900	200	27
10,000	3/3/900	450	12
7,500	4/3/900	600	9
3,600	5/5/900	1,250	4

* This system of nomenclature is based on the fact that one standard twisted yarn is represented by 1/900. When two such standard yarns are twisted together the resultant yarn is 2/900, etc. If two strands of 2/900 are twisted together, 2/2/900 results.

Figures given by Atkinson reveal that the breaking strength of continuous filament alkali-free glass tape is higher than that for similar staple filament tapes.

Table 11

Breaking Strength (Pounds) for Staple and Continuous Filament Glass Tapes

Width of Tape (Inches)	Thickness (Inches)					
	0-01		0-015		0-020	
	S	C	S	C	S	C
$\frac{1}{8}$	59	70	85	—	105	186
$\frac{3}{16}$	68	91	108	—	119	265
$\frac{1}{4}$	110	133	158	285	183	346
$\frac{5}{16}$	150	220	167	322	245	440
1	182	280	250	494	305	595
1 $\frac{1}{4}$	268	—	298	610	360	850

S = Figures for staple filament.

C = Figures for continuous filament.

The Manufacture of Glass Filaments. Atkinson (*loc. cit.*) has given details of the plants used for preparing both staple and continuous filaments.

For the production of staple filaments small glass marbles are melted in an electric resistance furnace, and the molten glass is

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allowed to flow through small orifices in the bottom, which is made of a precious metal alloy. The emerging glass filaments are blown downwards by means of high velocity steam jets, and the filaments are sprayed simultaneously with lubricating oil in order to minimise inter-filament friction. The filaments are finally spun on textile spinning machines in a manner similar to that used for cotton or wool yarn.

Continuous filaments are produced by drawing 102 or more of them from the furnace into a single filament which is wound on a high-speed bakelite tub. The filament in this instance is lubricated by passing it over an oil-soaked felt pad.

It is then twisted and ultimately woven into fabric. Continuous filaments resemble natural silk or artificial silk in appearance.

In addition to the ordinary form of glass silk, a newer type has become available recently. It is known as "weftless" material, and has threads only in the length direction. These are cemented together by a special type of impregnating varnish. Weftless varnished glass cloth is made in thicknesses of 0.002 inch and upwards, as both sheet and tape. It has been found very useful for conductor insulation and as a backing for mica.

Dielectric Strength of Glass Silk. In the unimpregnated state glass silk offers some advantage over other types of textile in respect of di-electric strength. The following test results (5) show the di-electric strengths of cotton, asbestos, and continuous and staple filament glass textiles, both before and after washing with boiling dilute soap solution.

Table 12

Dielectric Strengths of Cotton, Asbestos and Glass Fabrics Before and After Washing

Material	Average Dielectric Strengths (volts per mil.)	
	As Received from the Loom	After Washing
Cotton	94.5	88.5
Asbestos	58.3*	51.2
Continuous fibre glass	94.4	97.3
Staple fibre glass	92.3	99.6

* Sometimes asbestos is used on a cotton backing, and this gives substantially higher dielectric strengths.

ASBESTOS

Asbestos has been used, almost since its discovery in the remote past, for its fire and heat-resisting properties. It is, therefore, a possible competitor of glass fabric as an insulator in electrical machines operating at high temperatures. Asbestos cannot be woven into such fine cloths as those which are produced from cotton, silk, etc., and its use has been restricted therefore to purposes where relatively thick heavy cloths are convenient. One reputable manufacturer of asbestos cloths, for example, lists an unproofed cloth weighing $10\frac{1}{2}$ ozs. per square yard, for binding armatures, and this appears to be the lightest cloth obtainable. By comparison with cotton and silk fabrics, however, which weigh only an ounce or so per square yard, asbestos fabric is too thick and heavy for general insulation. Heavy fabrics, too, present difficulties in the impregnation process, and it is extremely difficult, if not impossible, to obtain smooth evenly impregnated insulating fabrics from them. There is, therefore, no indication that varnished asbestos cloths are serious competitors, either of the other well-established varnished cloths for general insulation, or of the recently introduced varnished glass silks for high-temperature work.

Chemical Properties. Asbestos is usually regarded as a chemically inert material, but its inertness varies according to its source and composition.

Tremolite asbestos is unattacked by mineral acids, crocidolite is only slightly attacked, but chrysotile is decomposed by both sulphuric and hydrochloric acids. These three types also behave differently on heating. Tremolite is not easily fusible, but chrysotile loses water at red heat and is fusible; crocidolite is readily fusible to a black glassy material.

Sources and Types of Asbestos. Crocidolite or blue asbestos, is derived from the South African mountains. Anthophyllite is mined in the United States in Idaho and Georgia. Canadian asbestos or chrysotile, and Italian asbestos or tremolite, are other forms of the mineral. Canadian chrysotile is mined chiefly in Quebec; and the tremolite is distributed in the mountain ranges of the Alps, the Urals and the Appalachians. Most of the world's consumption of asbestos is supplied by Canada, as this is considered to be the best.

Construction of Asbestos Fibres. Individual asbestos fibres are exceptionally fine and measure less than half a micron in diameter. They are naturally twisted together in bundles.

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Asbestos is essentially crystalline, and it is the peculiar aggregation of the crystals in elongated form which gives asbestos its fibrous character.

Asbestos fibres are, of course, solid in section.

Composition. The composition of asbestos varies somewhat according to the source, but all types have the element silicon in common, and most contain magnesium in addition to other elements. Thorpe (9) lists the following types of asbestos with their compositions.

Serpentine (chrysotile)	. $H_4Mg_3Si_2O_9$
Tremolite	. . . $CaMg_3(SiO_3)_4$
Crocidolite	. . . $NaFe^{11}(SiO_3)_2Fe^{11}SiO_3$
Anthophyllite	. . . $(MgFe)SiO_3$
Palygorskite	. . . $nH_8Mg_2Si_3O_{12}mH_2Al_2Si_4O_{12}.5H_2O$
Actinolite	. . . $Ca(MgFe)_3(SiO_3)_4$

Because of the variation in composition the colour of the various types of asbestos may be white, grey, yellow, green or blue.

Production of Asbestos Cloths. The mineral is disintegrated by special machines into separate fibres which vary considerably in length, from an inch or so to several feet.

The process of disintegration is akin to that used for raw cotton, and the fibres are gradually twisted into yarn which is ultimately woven into cloth.

Unlike the weaving of other textile fibres no size is used.

Properties of Asbestos Cloth. Comparative tests of asbestos cloth and glass silk on the heat-resisting properties of the two materials indicate that glass silk is superior in this respect. (5)

The table below gives the percentage strength retentions after subjecting the materials to 300° C. for five minutes.

Table 13
Strength Retention of Fibres on Heating

Material	Percentage Strength Retention calculated on Initial Strength
Continuous glass fibre . . .	87-92
Staple glass fibre . . .	85-95
Asbestos	54
Cotton	Too low to permit tests.

Because of the facts that asbestos has a comparatively high water absorption, and contains ferrous and other conducting salts its use is usually confined to low-voltage equipment.

Asbestos tape does not possess such good mechanical properties as glass tape, and consequently glass tape half the thickness of asbestos tape gives roughly the same strength. The use of the thinner glass tape is a very great advantage in the manufacture of electrical components.

RAYONS

VISCOSE

Viscose was born in 1891 when Cross, Bevan and Beadle discovered that alkaline cellulose reacted with carbon disulphide. The water-soluble product obtained was named viscose. Both viscose and cuprammonium silk are true regenerated celluloses.

Manufacture of Viscose. The raw material for viscose is cellulose, which is present in cotton, wood and other products, but the two former are the most important sources. Silk produced from cotton is much stronger than that from wood, but wood pulp is often used as the starting material because of its cheapness.

The cotton may be in the form of linters, spinning waste or rags, but these have to be specially treated before they can be used in viscose manufacture. The cellulose is obtained from the various forms of cotton by a succession of processes involving solvent extraction, boiling with alkali, scouring and bleaching, until a satisfactory pulp is obtained.

Special timbers, such as spruce and fir, are also selected for conversion into cellulose pulp, and the isolation of cellulose may be accomplished by any one of three processes—by treatment with calcium bisulphite, soda, or sulphate. The pulp obtained by the first process is known as sulphite wood pulp, and is generally considered to be the most satisfactory form for subsequent conversion into viscose.

Three modifications of cellulose are known and are designated by the letters α , β and γ , but the β and γ forms are unsuitable for artificial silk manufacture. The comparative analyses of sulphite wood and cotton pulps are given in the table below.

β and γ cellulose are differentiated from α cellulose by the fact that they are soluble in 17.5 per cent. caustic soda solution, whereas α cellulose is not.

In order to obtain viscose the cellulose pulp is first converted into alkali cellulose, which, for convenience, may be represented

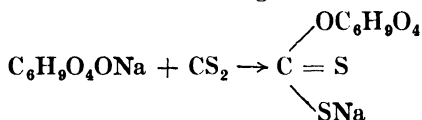
Table 14
Analyses of Sulphite Wood and Cotton Pulps

Pulp	Percentage Cellulose (Calculated on Dry Pulp)		Percentage Moisture	Percentage Resin (Cal- culated on Dry Pulp)	Percentage Ash (Calcu- lated on Dry Pulp)	Copper No.
	α	β and γ				
Sulphite wood	85-89	11-14	8-12	0.6-0.7	0.15-0.3	3.0 (10), (11)
Cotton.	98	1.8	—	0.34	0.12	0.89 (12)

by the formula :— $C_6H_5O_4ONa$, where $C_6H_{10}O_5$ is the original cellulose unit.

The pulp is steeped in a caustic soda solution (about 17.5 per cent. concentration), the solution is then removed partly by pressing, and β and γ cellulose dissolve into the waste liquid. The pressed pulp is then disintegrated and allowed to mature, during which process oxygen is taken up and the cellulose is depolymerised.

The alkali cellulose is then treated with carbon disulphide in a churn. Considerable heat is evolved during a reaction between the two reactants, and the cellulose finally assumes a brownish-red colour. Care is taken to keep the reactants cool. Sodium cellulose xanthate is formed according to the following equation :—



A good deal of the success of the process of viscose manufacture depends upon the purity of the two principal reagents—caustic soda and carbon disulphide—both of which are carefully checked for quality before use.

The xanthate is next transferred to a mixer where it is thoroughly mixed with water and caustic soda, to yield a viscose consisting of about 7.5 per cent. of cellulose and 7 per cent. of caustic soda. Several batches of xanthate may be blended together to ensure better uniformity, and the whole is then left to “ripen” at ordinary air temperature for several days; the liquid is filtered simultaneously to free it of suspended matter.

The xanthate solution is then fed through a pipe which ejects it below the surface of a specially selected liquid through a perforated jet.

The composition of the liquid in the spinning bath is important,

and many patents have been taken out for bath liquids. Their compositions are common in that they all include a mineral acid. The function of these liquids is to convert the viscose or sodium cellulose xanthate into cellulose filaments.

About fifty or so filaments are produced simultaneously through one perforated jet, and these are spun into a single thread. The average twist in the finished thread is usually about 2.5 to 3 turns per inch.

The thread then passes through a series of cleansing or purifying processes, involving washing to remove traces of acid and salts absorbed in the spinning bath; desulphurising with solutions like sodium sulphide which have the effect of removing sulphur; rewashing; bleaching with sodium hypochlorite; souring with dilute mineral acid; and a final and thorough washing.

Construction of Viscose Filaments. It will have been deduced already from the foregoing that viscose filaments are continuous; their diameter varies from 0.0005 to 0.0016 inch approximately. They are solid in section but possess irregular surfaces, the smoothness of which is modified by the treatment the viscose receives in the spinning bath. Smooth rounded sections like short bent bananas are obtained by treatment with sulphuric acid—salt, or dilute sulphuric acid—ammonium sulphate baths. Treatment with acid—salt—glucose gives a very serrated edge to the sections.

Composition of Viscose Filaments. Viscose filaments consist essentially of cellulose, but they may include, in addition, traces of impurities. The impurities likely to be present are sulphur, and ingredients used in the sizes.

CUPRAMMONIUM SILK

Manufacture of Cuprammonium Silk. Cuprammonium silk, like viscose, is produced either from cotton linters or waste, or sulphite wood pulp. The process consists, in the first instance, of dissolving the basic raw materials, and this is accomplished by two different methods.

Copper turnings are steeped in strong aqueous ammonia and the mixture is oxydised by means of atmospheric air which is blown into it. A complex solution containing about 3 per cent. of copper and 25 per cent. of ammonia is ultimately obtained, and this is used as a solvent for the cellulose.

The alternative method is to mix a freshly prepared basic copper salt, made by precipitation from sodium hydroxide or carbonate, and a copper salt, with cellulose, in a pulping machine.

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The compressed cakes are then treated with a mixture of ammonia and sodium hydroxide until an aqueous solution of cellulose is obtained.

Both types of solution are then filtered, freed from air and spun through jets, the filaments being coagulated in acid or alkali baths. The acid baths contain fairly strong sulphuric acid; and the alkali baths a mixture of caustic soda and glucose. In the stretch-spinning process, filaments as fine as those from natural silk can be obtained.

The spun thread is contaminated with copper compounds, more especially if made by the alkali process, but acid washing effects their removal. The thread is then washed free of acid and dried.

Construction of Cuprammonium Filaments. These, like viscose, are continuous and are of solid section. The two types are easily distinguished, for cuprammonium filaments are much more regular, being free from serrations and almost circular in section.

Composition of Cuprammonium Filaments. The filaments are really pure cellulose, but may contain traces of copper, acid, size constituents, etc.

CELLULOSE ACETATE SILK

Manufacture of Cellulose Acetate Silk. Cellulose acetate differs fundamentally from either viscose or cuprammonium silk. Whereas the latter two are obtained from cotton or wood pulp, merely by purification processes to yield ultimately substantially pure cellulose, cellulose acetate is a distinct reaction product. The original cellulose is modified considerably.

It is produced by the action of acetic acid and acetic anhydride on cellulose in the presence of catalysts. The first reaction product thus obtained is still insoluble in acetone, and it is further treated with more acetic acid at a higher temperature than before.

The product is precipitated from solution by dilution with water, washed, dried, dissolved in acetone or other solvent, and filtered. The clean, de-aerated cellulose acetate solution is then spun by passing it through a jet into baths of aqueous salt solutions, hydrocarbons, etc., or it may be handled by the stretch-spinning process. Alternatively the acetate solution, in a volatile solvent like acetone, is projected into a hot air cabinet, and in this way the solvent is evaporated to leave a dry cellulose acetate filament.

Construction of Cellulose Acetate Filaments. These are continuous, but vary in sectional shape somewhat, according to the manufacturer. On the one hand, some types resemble the

irregularly-shaped viscose filaments without, however, possessing such pronounced serrations, and on the other hand they may resemble the almost smooth circular sections of cuprammonium.

Composition of Cellulose Acetate Filaments. Cellulose possesses hydroxyl groups which are capable of esterification to form acetyl derivatives. The product used for the manufacture of silk filaments is not the triacetate but a mixture, possibly of the triacetate and cellulose (18).

There is, of course, also the possibility of the presence of traces of impurities from reagents used in manufacture.

Sizing, Soaping, Bleaching, etc. Before artificial silk yarn is woven into fabric it is sized, but special care is needed to select or compound the correct type of size. Materials like the water soluble natural gums—arabic and tragacanth, and dextrine or gelatine are used, sometimes with softeners like glycerine and turkey red oil. Solutions of natural resins—dammar and mastic, or metallic resinates and oleates, in aromatic hydrocarbons, have also been suggested as sizes for cellulose acetate (16).

Soaping is another process to which silk is sometimes subjected with the object of conferring softness on it.

Silk is not always a pure white colour, for the final colour depends to a large extent on the colour of the initial pulp. It is therefore treated with bleaching agents, and as with cotton, great care must be exercised to avoid over-bleaching and formation of oxycellulose.

Chemical and other Properties. Water has very little effect on artificial silks. The only noticeable effects are swelling of the filaments and a slight loss of strength.

Cellulose acetate differs from viscose and cuprammonium in its low average moisture content.

Table 15
Moisture Contents of Artificial Silks

Artificial Silk	Percentage Moisture Content (calculated on Dry Weight)
Viscose and cuprammonium	11-14
Cellulose acetate . .	8-6.5

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Lawrie (14) and Grier (15) have measured the increase in diameter in the fibres after immersion in water with the following results.

Table 16

Percentage Increase in Diameter of Artificial Silk Fibres after Immersion in Water

Artificial Silk	Percentage Increase in Diameter
Viscose	25-35
Cuprammonium	41-50
Cellulose acetate	9-14

Exposure of silks both natural and artificial to moisture, results in a considerable reduction in strength as the table below shows, and it is apparent that the artificial silks are inferior to natural silk in this respect.

Table 17

Retention of Strength of Natural and Artificial Silks under Moist Conditions

Type of Silk	Percentage Retention of Strength (Tenacity) under Moist Conditions (%)
Natural silk	75-80
Cellulose acetate	65-70
Cuprammonium	50-60
Viscose	45-55

Acids generally, whether inorganic or organic, under suitable conditions, attack artificial silks, probably producing hydro-cellulose. This attack is associated with embrittlement and loss of strength. It is essential, therefore, that any acids used for souring during the manufacture of the yarn should be completely removed ; moreover, the presence of acidic materials incorporated

in sizes or as antiseptics, is another possible cause of silk degradation.

Boiling alkaline solutions have a marked tendering effect on artificial silks, and in the case of the acetate, it is hydrolysed. A carefully controlled treatment with alkali is, however, beneficial, as in mercerisation.

NYLON

Nylon is a newcomer into the field of textile fibres, being the outcome of research work of Carothers and others, covering the period 1928-37. It has remarkable properties, and it appears to be an easy prediction that in the post-war years, when supplies are more generally available, nylon will displace many other synthetic and natural filaments for certain purposes.

Because of a severe restriction in supplies the exploitation of nylon on a large scale is temporarily prevented, but considerable exploratory work on a small or laboratory scale has been, and is, being carried out.

The Manufacture of Nylon. Nylon is the highly polymerised reaction product from hexamethylene diamine and adipic acid.

Hexamethylene diamine, 264 parts ; and adipic acid, 332 parts, are heated with commercial xylene, 600 parts at 218° C. for about twelve hours or more. By this means, in one operation, a condensation is effected between the amine and the acid, and the reaction product is polymerised to a high degree.

It is obtained in a pure state by pouring the whole mixture into a large volume of alcohol and stirring vigorously. Nylon separates as a white granular mass, and it is washed thoroughly with alcohol and dried.

Other possible dibasic carboxylic acids which give a similar reaction product are pimelic, suberic and sebacic acids or their esters. Other possible diamines are the tetra, penta and decamethylene diamines.

Nylon is also made by the condensation of ω -aminocarboxylic acids or their lactams ; suitable amino acids are ω -amino caproic—pelargonic or—undecylic acids. Pelargonolactam, 10 parts, and mixed xylenols, 12 parts, are heated together at 215° C. for about two hours and the xylenols removed under vacuum.

Loasby (23) gives further details on the reaction between adipic acid and hexamethylene diamine and describes the product as nylon salt. This is dissolved in water and purified. The water is subsequently removed in an autoclave and the resultant salt con-

verted to an amide. The amount of water removed and the ultimate degree of polymerisation of the product is governed by the duration of the reaction.

The granular nylon is converted into a filament by three different processes. Two of them are similar to those used for the production of artificial silk filaments, namely, wet spinning and dry spinning. The third is distinctive in that a filament is obtained direct from the molten polymer. The nylon is melted in a pressure vessel to a thick yellow liquid and this is extruded at high temperature through spinnarets.

In the wet spinning process the nylon is dissolved in a phenolic solvent, like ordinary phenol or cresol, and the solution is then projected through jets into a spinning bath containing a suitable precipitating liquid. Caustic soda solution has been used satisfactorily as a precipitant. Before the resulting threads can be woven they have to be washed thoroughly and dried. Other solvents for nylon are formamide and acetic acid.

The dry spinning process merely consists in projecting a solution of nylon in the above-mentioned solvents, or in anhydrous formic acid, into a warm air chamber. This has the effect of evaporating the solvent and leaving behind a dry nylon thread.

Nylon filament as obtained by any of these three methods has to be subjected to a cold drawing process in order to modify its natural excessively high extensibility, and to orientate the molecules so that they lie parallel to the long axis of the filaments. During the cold drawing the filaments are stretched to between twice and seven times their original length. The longitudinal molecular orientation of the filament yields a structure which is similar to that of the natural filaments.

Construction of Nylon Filaments. Nylon filaments are solid in section and continuous. It is possible to spin filaments as fine as 0.2 denier or less.

Composition of Nylon Filaments. Nylon filaments are essentially polyamides with a chain molecular formation of the type— $\text{NH}(\text{CH}_2)_n\text{NH.CO}(\text{CH}_2)_m\text{CO.NH}(\text{CH}_2)_n\text{NH}$, etc. The molecular structure closely resembles the protein structure of natural silk fibres. The molecular weight of the polyamides varies between 5,000 and 50,000.

Chemical and Other Properties. Sarre describes the simple polyamides as very viscous masses, varying in colour from colourless to brown. Their specific gravities are between 1.04 and 1.08 and they melt in the range 150°–270° C. (19).

Nylon has good chemical resistance, in that it resists attack by alkalis. Only slight degradation occurs with 40 per cent. caustic soda at 90° C. (20) It is, however, hydrolised by strong mineral acids. At room temperature, in sulphuric acid, nylon loses 5 per cent. of its strength in an hour. At 90° C. it loses 5 per cent. of its strength in sixteen minutes and 25 per cent. in six hours. It is insoluble in alcohol and in water, although the latter has an effect on both tensile strength and extensibility. The tensile strength of nylon measured in grams per denier, has been given as 5 when dry and 4.5 wet. Extensibility increases, however, under wet conditions, from 20 to 30 per cent.

Nylon loses its strength on prolonged heating. At 100° C. 20 per cent. of the strength is lost in seven days, but sixty days are required at 70° C. to cause a similar loss of strength.

Nylon is a very elastic fibre, for it recovers completely when stretched up to 8 per cent. Even when stretched up to 16 per cent. there is a 91 per cent. recovery.

Manufacture of Nylon Fabrics. Nylon warp yarns, like yarns of other textile materials are sized, and the principal sizes used are based on methyl methacrylate resins or on partly saponified polyvinyl acetate resins. Casein, gelatine and linseed oil have also been used for sizing.

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CHAPTER IV

THE IMPREGNATING VARNISH

VARNISHED cloths are made by the application of an impregnating composition or varnish to a suitable flexible support, the whole being solidified by what is known as a drying process.

The description, impregnating varnish or impregnant, is rather a misnomer, for after the first application of it, when it does or should thoroughly impregnate the support, successive applications are in the nature of finishing coats, for thereafter there is virtually no impregnation. It is then chiefly a matter of building up the initial one-coat impregnated product to a convenient thickness, in order to obtain a specified overall breakdown voltage. Thus, although the liquid composition is commonly described as an impregnating varnish, it does, in effect, perform the dual rôle of impregnation and finishing or building up. It is not common practice that special compositions are used for impregnation and different ones for finishing, but there are indications that this will not always be the case.

What is an impregnating composition or varnish? This is not a simple question to answer, for there are many different types of varnish, each used to obtain a specific property in the final product. Special properties are generally obtained only at increased cost, and since these properties are not always required for all purposes, cheaper varnishes are produced to meet everyday and less exacting demands. Moreover, to complicate the matter further and to double the number of possibilities, the electrical trade favours two types of insulating fabric—yellow and transparent, or black and opaque—and both types are required with special properties.

It is perhaps simplest to consider the common yellow and transparent type of impregnating varnish first. It comprises four main constituents :—

1. Drying oil.
2. Resin.
3. Thinner.
4. Drier.

The drying oil component is a vegetable product, chosen, primarily, because it possesses the property of solidifying or drying under the action of heat and/or a stimulator or drier.

The Mechanism of the Drying Process

The solidification or drying of varnishes and allied products occurs as the result of three distinct types of mechanism, namely, evaporation, oxidation and polymerisation. Often two or more types of drying mechanism occur for an individual varnish. They may follow one upon the other, or they may occur simultaneously: It is possible for evaporation and oxidation or polymerisation to take place at the same time; for oxidation and polymerisation to occur together; or for all three drying processes to take place, at least to some extent, simultaneously.

Evaporation. The simplest means of converting a wet film of impregnating varnish into a dry one is by evaporation of the solvent or thinners. In almost every varnish composition some volatile matter is present, and it is essential to remove this to obtain a satisfactory film. The presence of the solvent prevents or retards oxidation or polymerisation of the non-volatile constituents.

The rate of evaporation of a solvent is controlled by a number of factors; probably the most important is the vapour pressure of the solvent itself, for the rate of evaporation is directly proportional to the vapour pressure.

Evaporation of a solvent from a substantially non-volatile material is really a diffusion process. Molecules of the solvent at the surface of the wet film diffuse into the air layer immediately above, and if they are not removed mechanically, by means of an artificial draught, the concentration of solvent molecules in the air increases. As the concentration increases the rate of evaporation or diffusion from the film decreases. Loss of solvent molecules from a film near its surface causes the internal equilibrium to be upset, and molecules of solvent in the film, remote from the air-liquid interface, diffuse towards the surface of the film in order to re-establish equilibrium.

Thus if solvent molecules which escape from the wet film into the air are removed continuously, by a strong artificial draught or good ventilation, evaporation of the solvent from a film will continue, for every chance is afforded for fresh solvent molecules to escape from the film into the air, because of the low concentration there, and as molecules near the surface of the film are lost, others will diffuse from inside the film towards its surface. Therefore, adequate ventilation is an essential feature in the drying plant for any varnish containing a volatile solvent.

As the prevailing temperature increases, the rate of evaporation of the solvent increases also. The vapour pressure of liquids increases with rise in temperature. If no external heat is applied to a drying film, it will become cold, because heat will have been extracted from it to supply the heat of vaporisation of the solvent. It should be realised that when the solvent is in the varnish film it is present as a liquid, but when it evaporates into the air it changes its state and becomes a vapour. Heat is necessary to produce this change of state from liquid to vapour, and the varnish film itself, the surface on which the film is applied, and the surrounding air have to supply it. This results in a general fall in temperature which, as indicated already, causes a reduction in the vapour pressure of the solvent with a simultaneous reduction in the rate of evaporation.

Thus even for so-called air drying lacquers and varnishes, which dry solely by evaporation of solvent, the application of heat is advantageous in increasing the rate of drying; firstly, because it increases the vapour pressure of the solvent, and secondly, because it prevents reduction of temperature of the film and its surroundings consequent upon evaporation.

When evaporation is assisted by the application of heat, care must be taken to avoid excessively rapid evaporation, for this causes bubbling.

It is obvious also that a reduction of pressure can assist in the evaporation of solvents from films.

Thickness of film plays an important part in controlling solvent evaporation. The thicker the film the slower the evaporation. This is particularly noticeable with exceptionally thick films. Varnishes incorporating even very volatile solvents, will remain plastic for hours or days, because of retained solvent, if applied thickly. Thick films from some varnishes tend to form a crust-like barrier at the air-varnish film interface, and this impedes further solvent evaporation.

If it is essential to obtain a thick film on a surface, it is preferable to accomplish this by the application of several thin coats.

If high concentrations of solvent vapour are permitted to collect above a drying film, they will displace air and prevent or retard the normal oxidation of an oxidisable film.

There are many other factors which influence the rate of evaporation of solvents from films, but they are of little interest

to the varnish user. On the other hand, they are of fundamental importance to the varnish maker. These additional factors include the effect of the presence of other solvents and of the non-volatile film constituents, the specific heats of the individual varnish constituents and the heat of vaporisation of the solvent or solvent mixture.

The effect of the non-volatile constituents of the film is very important, for it varies considerably with different types of compounds. Some non-volatile constituents possess such strong affinity for solvents that although the major part of the solvent evaporates from the film, a proportion is held back tenaciously. This phenomenon is known as solvent retention.

Pronounced solvent retention is objectionable, for it keeps the film in a soft or sticky condition for long periods of time, rendering it unsatisfactory for handling and more susceptible to temperature changes because of its increased thermoplasticity, and decreases its water resistance. Moreover, solvent retention, unless the solvents are carefully selected, may cause a substantial reduction in insulating properties.

Solvent retention is a very real defect especially when it is realised that shellac films, for example, produced from shellac and industrial alcohol, retain appreciable amounts of the solvent for months after the film is apparently dry.

In one respect, solvent retention is an advantage. The un-evaporated solvent acts as a plasticiser, conferring flexibility upon the varnish film. It may assist the adhesion also.

It is easy to determine whether a given varnish dries solely by evaporation of solvent or not. If the solvent in a varnish is industrial alcohol or hydrocarbon, and the dry film is gently rubbed with whichever solvent was present initially in the varnish, it will redissolve easily if drying is the result of evaporation only. Where other drying processes are involved in film formation, such as oxidation or polymerisation, the film will not be re-dissolved on application of the original solvent, but it may be softened or swelled.

Oxidation and Polymerisation. Since these two processes of drying occur simultaneously they will be considered together.

Vegetable drying oils, such as linseed, tung, oiticica and perilla oils and dehydrated castor oil—a drying oil which is derived from the non-drying castor oil, are comprised of mixed triglycerides. A mixed triglyceride is an ester compound in which different fatty acids are in combination with the same glycerol molecules. The

fatty acids may be saturated or unsaturated, although in drying oils unsaturated fatty acids predominate.

It is the presence of unsaturated bonds which confers drying properties on an oil.

According to Long (1) the drying or transition of an oil from the liquid to the solid state takes place in four distinct stages.

In the first stage polar bodies are formed as the result of oxidation. These associate to form higher molecules which in turn form micelles. Free liquid is then imbibed by these colloidal particles causing gellation. The gelled film then oxidises further and hardens off.

The precise drying mechanism is, however, still the subject of conjecture and discussion. It seems reasonable to assume that both chemical and colloidal influences are involved.

Two important factors must be considered in film formation consequent upon oxidation and polymerisation, and they are both concerned with chemical constitution. The first is the function of unsaturated bonds in the acid radicals. Drying power appears to increase with the number and the location of unsaturated bonds in each fatty acid radical. Thus a triglyceride derived from oleic acid which possesses one unsaturated bond only, does not dry to any practical extent. A triglyceride derived from linolenic acid, which is a major constituent acid of linseed oil, possesses pronounced drying properties. Linolenic acid contains three double bonds. In addition to linolenic and oleic acids, linseed oil contains also linolic acid and a small amount of saturated acids. The latter possess no drying properties at all. Where more than one unsaturated bond exists in an acid radical, the situation of the bonds becomes important also. If two bonds are conjugated, *i.e.*, they are situated next to each other in the molecule, then they possess enhanced reactivity. Wood oil or tung oil dries much more rapidly than linseed oil, and this may be explained by the fact that it is comprised chiefly of elæostearic triglyceride, the acid portion of which contains three double bonds which are conjugated.

The second important factor concerning film formation connected with chemical constitution is the presence of the trihydric alcohol, glycerol, in the oil molecule. This is of considerable importance, for if glycerol with its three reactive hydroxyl groups is replaced by lower alcohols, such as ethyl alcohol (monohydric), or ethylene glycol (dihydric), the resultant esters derived from suitable unsaturated acids do not exhibit drying properties to an

appreciable extent, if at all. A triglyceride molecule can be likened to a hub from which three spokes extend symmetrically on different but parallel planes. The $\text{CH}_2\text{—CH—CH}_2$ chain of the glycerol corresponds with the hub, and the unsaturated fatty acid radicals, characteristic of drying oils, are represented by the spokes. Thus each spoke is capable of uniting with a spoke of another new system. So that one glyceride system with its three spokes is capable of uniting with three other glyceride systems. In this way glyceride molecules associate together and larger molecules are built up.

If, as is the case with linseed oil, some of the spokes consist of saturated or only slightly unsaturated fatty acid radicals, union with other systems does not occur at all through these particular spokes. Hence the extent to which larger molecular arrangements can be built up is diminished.

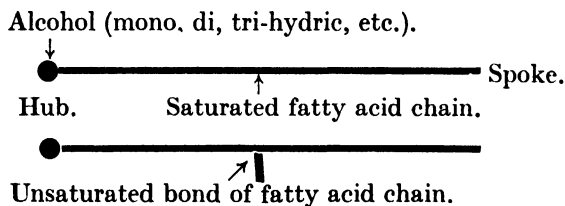
If the glycerol hub is replaced by a glycol hub ($\text{CH}_2\text{—CH}_2$), only two unsaturated fatty acid spokes are possible, and any tendency to unite with similar systems is reduced considerably. If perchance one of these spokes is represented by a saturated acid, the chances of union are reduced to one only.

With a monohydric alcohol hub (CH_3)—only one spoke is available for union.

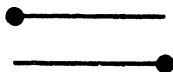
Wood oil consists almost exclusively of elæostearic triglyceride with its conjugated bonds, which means that in the majority of the glyceride molecules three highly reactive spokes are available for union. This accounts for the rapid drying shown by wood oil by comparison with linseed oil.

Esters from higher alcohols than glycerol, such as pentaerythritol, with drying oil fatty acids, have been prepared on the small scale. With the increased number of reactive spokes available (four), they should exhibit, theoretically, outstanding drying properties.

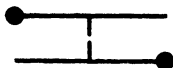
The following diagrams give some idea of possible polymerisation mechanisms with various types of ester.



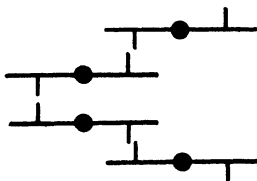
1. Esters of monohydric alcohol (methyl alcohol) and saturated fatty acid. (1 spoke.) No polymerisation.



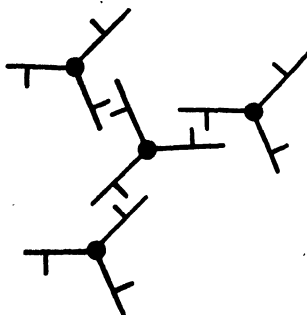
2. Esters of monohydric alcohol (methyl alcohol) and unsaturated fatty acid. (1 spoke.) Possibility of some polymerisation and drying.



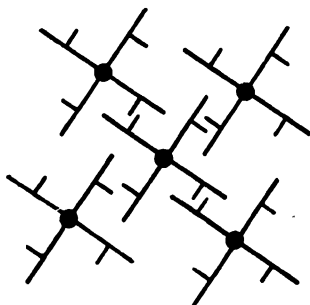
3. Esters of dihydric alcohol (ethylene glycol) and unsaturated fatty acid. (2 spokes.) Increased possibility of more extensive polymerisation and drying.



4. Esters of trihydric alcohol (glycerol) and unsaturated fatty acid. (3 spokes.) More extensive polymerisation and drying than 3.



5. Esters of higher alcohols (pentaerythritol) and unsaturated fatty acid. (4 spokes.) Theoretical possibility of more extensive polymerisation and drying than 4.



It is obvious from the foregoing that the nature of the alcohol present in an ester exerts a very important influence on its drying properties.

In the early stages of the drying process it is at the double bonds where oxidation occurs. Divergency of opinion exists concerning the type of oxygen compound formed. Suffice it to state that oxygen definitely attaches itself to the oil molecule, and according to Long the polar bodies formed thereby assist the formation of larger molecules.

With vegetable drying oils at ordinary temperatures, oxidation and polymerisation do not proceed at a substantial rate as soon as the film is applied. An induction period is observed during which no apparent change in the film occurs. One explanation for the induction period is that during this time natural anti-oxidants or inhibitors in the oil retard the normal oxidation process. After perceptible oxidation has commenced, however, the rate of oxidation gradually increases and then finally diminishes. During the period of increasing oxidation rate, the oxy-compounds which are formed are believed by some to act as catalysts for further oxidation and drying.

Many physical factors and formulation modifications exert a pronounced influence on the drying rate of a film of varnish. Obviously a plentiful supply of oxygen in the form of ordinary air is of primary importance. If the air supply is restricted because of inadequate ventilation, whether in a drying room, or in a stove or tower, the rate of drying will be reduced.

Drying rate increases considerably with temperature. Even temperatures slightly in excess of normal air temperature cause a substantial increase in the drying rate of varnishes which dry substantially by oxidation. Drying may be accelerated also by exposing the film to infra-red rays.

Exposure to ultra-violet light is also beneficial, but it is not essential for drying. The relative humidity of the air exerts a slight retarding influence on the rate of drying at lower temperatures, but its influence is almost undetectable at higher temperatures.

Damp, foggy conditions sometimes exert a pronounced retarding effect on air drying varnishes. The retardation is not due primarily to the presence of water vapour in the air, but may be due to the presence of other extraneous matter associated with fogs, especially if the surface has been exposed before varnishing. These adverse conditions, fortunately, would rarely be encountered inside factories using insulating varnishes.

Driers

The commonest way of increasing the rate of drying of a varnish is to introduce a drier or catalyst. These vary considerably in their effectiveness. Cobalt compounds are the most powerful driers known, but manganese driers are also used sometimes, although they are not so effective as cobalt. Both cobalt and manganese compounds are said to promote oxidation and to favour *surface drying* of a film. Lead driers, however, have much less influence on the drying rate than the two former driers, and they promote *through-drying* in the film as distinct from surface drying. Combinations of driers are employed also to achieve certain results, for they often exert a greater influence than individual driers.

The drying process of vegetable drying oils can be accelerated by treating the oils in bulk prior to, or during manufacture, of the varnish. The oils can in fact be partly oxidised or polymerised in advance. This means that after the application of the insulating varnish to the fabric, the treatment necessary to effect solidification of the varnish film can be curtailed appreciably, because the drying oils have already been partly solidified during or before the manufacture of the varnish.

Resins

Insulating varnishes based entirely on vegetable oils are not entirely satisfactory. The dried films lack strength and are easily damaged; they may also suffer from excessive surface tackiness; low dielectric strength initially and under moist conditions; poor resistance to decomposition by heat; a tendency to disintegrate on storage under warm, moist conditions; and many

other defects. With wood oil alone, for example, it is practically impossible to obtain a smooth even film without considerable skill.

For these reasons it is necessary to incorporate resins of various types in the oils to obtain the maximum of desirable properties. There are two types of resin which may be incorporated—natural or synthetic, but the resins of the latter type are the most valuable. It is, in fact, because of the availability of synthetic resins that it has been possible to produce not only vastly improved insulating fabrics during recent years, but also insulating fabrics with unusual properties for special purposes.

Many synthetic resins of the phenol-formaldehyde type are oil-reactive. This means that when they are heated with drying oils they combine with them and induce considerable polymerisation; the rate at which polymerisation, molecular growth, or solidification occurs is much greater than with oil alone, or with oil and natural resin mixtures under the same conditions. Moreover, not only is this solidification more rapid during the actual manufacture of the impregnating varnish, but during the subsequent drying process on the cloth also. Furthermore, the extent to which polymerisation occurs is greater. From this it follows, therefore, that selected synthetic resins of the phenol formaldehyde type provide not only an increased output of varnished cloth, because of acceleration in the rate of drying or solidification, but improved electrical properties in addition, because of the extensive polymerisation of highly complex molecules.

There is another type of synthetic resin which is used to a large extent in impregnating varnishes, known as an alkyd resin. These resins may be used as such without the addition of vegetable drying oil in the free state. They contain the constituent acids of drying oils, however, but these are in the combined state and are securely linked with glycerol and phthalic anhydride. Alkyd resins, like phenol formaldehyde resins, possess the property of easy and extensive polymerisation.

In addition to the synthetic resins mentioned already, there are others which may be used, but a discussion on them is beyond the scope of this book. These include, urea and melamine formaldehyde, coumarone, polystyrene, polyvinyl, maleic, acrylic, and silicone resins.

Thinners or Solvents

The thinners in the impregnating varnish are used merely as a means of reducing the consistency of the varnish to a state suitable for application to cloth by dipping or spreading. Once

they have performed this function it is essential that they are evaporated as quickly as possible. Great care is necessary in the selection of the thinners, for they perform an important rôle in giving adequate flow to the applied film. Wrong choice of thinners may result in the development of long tears or "curtains" on the finished cloth. The two most important properties of thinners are their solvent power for the non-volatile ingredients of the varnish and their speed of evaporation. If the solvent power of a thinner is deficient, additions to the varnish, especially if large amounts are necessary to obtain a workable consistency, will cause precipitation of some of the constituents of the varnish. This unsatisfactory condition, evidenced by a faint opalescence or a strong turbidity, must be avoided at all costs. The balance of the varnish is upset and the solid precipitated particles will cause electrical troubles in the film of the insulating cloth. A good insulating varnish should absorb reasonable amounts of thinners without showing signs of turbidity, and should remain clear and transparent after thinning, at least for a week or so. Excessive dilution of insulating varnishes, that is, if varnishes are thinned with more than their own volume of thinners, should not be attempted, unless a thinner has been carefully selected for the purpose. If a user contemplates thinning excessively to accommodate a certain application process, he would be well advised to refer back to the manufacturer of the varnish for technical advice on the matter, before proceeding.

The common thinners used are white spirit ; distillate which is a similar petroleum hydrocarbon to white spirit but with a lower evaporation rate ; coal tar naphthas and xylol ; and if certain types of synthetic resins are present in the impregnating varnish, special thinners such as butyl alcohol, cellosolve, cyclohexanone etc., may be necessary. Mixtures of thinners to obtain certain results or to reduce cost are by no means rare.

In designing an insulating varnish for fabric it is best to adjust its composition so that it will permit thinning by the cheap readily-obtainable thinners of petroleum type, and this is the normal practice. Nevertheless, in attempting to obtain certain properties in a special type of varnish abnormal combinations of thinners may be necessary.

It is always advisable, therefore, for the varnish consumer to ask for advice, not only on the quantity of thinners he proposes to use, but on their general suitability.

Where simple thinners like white spirit, petroleum distillate,

etc., are required, the proofer often purchases these directly himself from a petroleum company or other suppliers, but where complicated thinner mixtures are necessary, much trouble is avoided if he purchases the mixed thinners, ready for use, from the varnish manufacturer. In so doing he will put the whole onus of successful thinning on the varnish manufacturer, and this is the most satisfactory procedure.

The other important property of a thinner is the rate of evaporation or volatility, for if it evaporates too quickly the applied film of varnish will be prevented from flowing evenly on the cloth; on the other hand, if its evaporation rate is too low, the retained thinner will retard the drying or solidification.

Thinners, too, vary in their degree of inflammability, and to lessen the fire risk thinners should be chosen with flash points appreciably above the normal room temperature. Thinners with flash points above 90° F. are usually considered safe.

Asphaltums

The black insulating varnish may contain all the ingredients already enumerated for the yellow or transparent type, with the addition of a natural asphaltum or petroleum bitumen to provide the black colour. The introduction of an asphaltum or bitumen into a varnish makes formulation much more complicated, especially if certain types of synthetic resin are present. These difficulties can, however, be overcome by experienced formulators, and first class black insulating varnishes are available.

The introduction of an asphaltum or bitumen into an impregnating varnish tends to reduce the rate of oxidation or polymerisation, unless special compensating adjustments are made, to reduce the resistance to lubricating and transformer oils, and to reduce the resistance to crushing and abrasion. On the credit side, however, asphaltums and bitumens tend to improve chemical and water resistance and often give somewhat higher dielectric strengths. Where blackness is obtained by the introduction of black pigment, and this, with a little practice, is readily detected by rubbing the varnish on a glass plate and viewing it by transmitted light, the varnish should be regarded as suspect until dielectric strength tests have been made. Carbonaceous material, of which black pigments mainly comprise, is actually a good electrical conductor, and consequently it is effective in reducing dielectric strength. The extent of the reduction of this important property depends upon the amount of black pigment present.

There is, moreover, no need to incorporate pigments to obtain blackness or opacity.

Comprehensive details of the properties of all the important constituents of impregnating insulating and other varnishes is given in another treatise by one of the authors (2).

Modifications of the Varnish

Some proofers insist on an impregnating varnish with good "building" properties; in other words, on a varnish which gives a good film thickness with the minimum number of coats. This may be achieved by two methods. Firstly, by using a varnish in which the ingredients are in a low state of polymerisation, and from this it follows that only a small amount of thinner is necessary to reduce the varnish to application consistency. The bulk of the applied varnish, therefore, is non-volatile material, remains behind on the cloth, and thus assists in increasing its thickness.

This method may be satisfactory if the cloth has already received a first impregnating coat and it is merely necessary to apply further coats in order to build up to a required thickness. Slightly polymerised constituents are not, however, by any means, suitable for use in impregnating insulating varnishes generally, for they possess certain other serious defects.

The second method of improving "build" is to use a varnish with reduced impregnating properties.

Slightly polymerised varnishes have great penetrating power, but highly polymerised varnishes can be made with little or no tendency to penetrate. The varnish is so designed that it does not penetrate the fabric completely, but tends to remain upon the surfaces. There are, however, objections to this method of increasing impregnated fabric thickness, and these are discussed at length in Chapter VIII.

The formulation of a satisfactory impregnating insulating varnish is therefore a very difficult proposition, and because of the many diametrically opposite factors included, it is often merely the best compromise that is devised.

The storage of insulating varnishes is a very important factor which is apt to be overlooked. Too often it is completely ignored.

There are many important properties of insulating varnishes, and these have been enumerated in comprehensive form in the Introduction. These properties are achieved only by careful formulation and extreme care in manufacture, but mishandling

during use, or storage at the customers premises, can undo all the painstaking work on the part of the varnish manufacturer, and cause irreparable harm. Bad storage can result in complete destruction of the varnish from an insulating point of view.

Insulating varnishes are carefully balanced products both for the non-volatile constituents and for the thinners, and this balance is easily upset by careless storage.

It may be taken as a general rule that all varnishes, irrespective of type, should be stored at a good even temperature. The subject of varnish storage is dealt with in Chapter VI.

Some proofers doctor the impregnating varnishes they receive with the object of eliminating defects, modifying them in such a way that they preserve for themselves a certain amount of secrecy regarding their composition. There is, however, considerable danger in making such adjustments to a varnish of unknown composition. It is preferable to take the varnish manufacturer into confidence and permit him to evolve a varnish with all the desired characteristics. Experience has shown that proofers' ideas of the most satisfactory varnish vary appreciably, and this in itself makes for originality in the final product. In other words, a varnish which a varnish-maker produces specifically for one proofer will probably not be suitable for or fit in with the ideal conceptions of any other proofer.

The most common additions to varnishes made by proofers, apart from thinners, are driers and plasticisers. If improved drying properties or flexibility are desired these are best produced by the varnish manufacturer, without the risk of introducing other defects.

REFERENCES

1. "Review of Driers and Drying," Bennett, London, 1940, 5.
2. "Varnish Constituents," Chatfield, 1944. Leonard Hill Ltd.

CHAPTER V

THE MANUFACTURE OF VARNISHED CLOTH

THE information in this chapter is based on the assumption that the textile supports are ready for the application of the impregnating varnish. Firstly, we must ask ourselves what the manufacture of varnished cloths involves. In short, it is the application of an impregnating varnish to provide a smooth continuous liquid coating, and the subsequent conversion of this liquid coating into a tough dry film permitting the manipulations of electrical component manufacture. It is a process which needs very strict control, for any indifference or inexperience in this respect can ruin both an excellent textile support and a carefully formulated varnish.

Successive coatings are applied until a thickness is obtained to give the required total dielectric strength.

Tower Construction

The bulk of varnished cloth is made by what is known as the Tower process. The drawing on p. 76 gives details of the construction of this type of plant.

The tower is really a tall rectangular box ranging in height from 30 to 50 feet. It has double-cased sides, the intervening space between the inner and outer walls being packed with heat-insulating material to prevent large heat losses.

The tower is wide enough to accommodate easily the usual width of cloth, *i.e.*, it is about 4 feet 6 inches wide, and is about 4 feet deep. Of course, more than one piece of cloth can be coated at the same time if a larger tower is used, or if batteries of towers are installed.

A trough is fitted at the base of the tower and contains a guide roller somewhere near its bottom. The trough is filled with impregnating varnish. At the top of the tower another and larger roller is fitted, and above this an adjustable ventilator.

The tower is normally heated by steam coils arranged practically up its full height, except for a few feet which are left free of heating coils near the bottom. The reason for this is explained later. Another method of heating is to pass preheated air into the base of the tower.

The fabric is fed from a roll outside, and passes down through

the impregnating varnish in the trough, under the guide roller near the bottom, and then vertically up the tower. It continues upwards until it reaches the top roller, and after passing over this it travels downwards again and ultimately out of the tower, where it is re-rolled.

As the fabric passes through the trough of varnish it is impregnated with it, and the fabric, with the wet impregnating varnish, slowly moves upwards into the heated tower. During its journey upwards the volatile thinner or solvent in the varnish is first driven off, and then the non-volatile varnish film begins to oxidise and polymerise. It is essential that the varnish film is sufficiently dry or "set" to pass over the top roller without suffering any damage.

If the varnish film is at all sticky it will adhere to the top roller, and as it is forcibly separated to proceed on its downward journey, small amounts of semi-dried varnish will be wrenched out of the fabric and left adhering to the roller. This is known as "picking," and the resultant insulating cloth will have a very uneven appearance, and may even be bare in places, or pin-holes may be introduced. Whatever type of film disruption is caused it is most undesirable in an insulating cloth, and every precaution is taken to avoid it.

The varnish film is assisted into a sufficiently dry condition, to pass undamaged over the top roller, by adjustments which can be made both by the varnish maker and the proofer. The varnish maker can provide a rapidly drying material by making modifications in the formula of the varnish, or the proofer for his part can pass the coated fabric through the tower at a reduced rate or increase the temperature in the tower. Reduction of speed means a simultaneous reduction of output and such a modification is not favoured. Sometimes higher temperatures are attained, but this is not always possible with the steam-generating plant available. In the long run, information on both the economical running speed and the most convenient temperature are supplied to the varnish or impregnant maker, and it is left to him to formulate a varnish to suit these conditions.

When the varnished cloth leaves the trough, it passes into the heated zone of the tower and immediately the volatile thinners of the varnish begin to evaporate rapidly. After a few feet of travel in the heat they are substantially removed and the residual non-volatile film begins to solidify or dry. By the time the top roller is reached it is dry enough to pass over it without damage, and

then, on its downward journey, the drying process is completed. The extent of the drying process which is completed during the downward journey, depends upon the construction of the tower. Some towers have steam coils arranged on one side of the ascending cloth only ; others have coils arranged on both sides. It is not the usual practice to include heating coils on the downward side of the tower, but some drying occurs here nevertheless, because hot air is carried over, in addition to some conduction of heat. In certain towers heating coils are arranged on the downward side also, and thus practically the whole of the journey through the tower is effective in drying the varnish.

From a consideration of the section devoted to the mechanism of the drying process (see Chapter IV), it is apparent that an ample supply of oxygen is necessary for drying. In the early stages of the drying process it has been explained that large volumes of thinner evaporate, and these, together with volatile oxidation products of the drying oils, collect in the tower. In order to provide an adequate supply of oxygen in the form of air, and to accomplish the removal of volatile matter, the towers are fitted with ventilators at the top.

When the varnished cloth leaves the tower it should be in a sufficiently dry condition to roll without the risk of adjacent pieces of cloth sticking together. There is also another point which has to be considered—the varnished cloth must be cool before rolling. This is ensured by reserving the downward run of the tower for cooling ; in other words, no heating coils are installed on that side ; all the drying is accomplished during the upward journey. Alternatively, if the whole of the journey through the tower is used for drying, the varnished cloth, on emerging, is cooled by allowing it to pass through the air for several feet before it is rolled ; to make certain that it is really cool it is sometimes passed between cooled rollers.

If varnished cloth is rolled in the hot or warm condition, the heat it contains is kept entrapped and cannot dissipate. This provides ideal conditions for spontaneous combustion, with further generation of heat, which may result in serious tendering of the material, or in bad cases, even charring or ignition. To avoid this, if there is any suspicion that the varnished cloth is not quite cool before rolling, the proofer may re-roll twenty-four hours afterwards, and perhaps again before dispatch. All the causes of spontaneous combustion are explained in Chapter VI.

Process Conditions

When the temperature in the tower is adjusted to a constant level and the running speed has been fixed, the only other adjustment left for the proofer is to keep the viscosity of the impregnating varnish constant. This is perhaps the most difficult control of all to exercise satisfactorily.

In the beginning, the viscosity of the insulating varnish has to be regulated so that with a given rate of movement of the cloth a coating of varnish of convenient thickness is obtained. The thickness of the applied coating is of vital importance. If the coating is too thin, pin-holes will be left in the cloth when the volatile matter is driven off, because of insufficient non-volatile residue to completely seal all its interstices. If the coating is too thick it will be very difficult to control its flow.

Before the proofer can decide upon the correct viscosity of application, especially of a new varnish, he will probably have to make two or three trial runs through the tower. Varnishes of different types with the same viscosity do not necessarily yield films of the same thickness. The volatile contents of the varnishes may vary considerably, but some guide to a satisfactory viscosity for application is given by an actual determination of the volatile content of the varnish. The determination of the volatile content of a varnish is a relatively simple matter and the procedure is outlined in Chapter IX.

As soon as the applied varnish meets the heat in the tower, its viscosity is suddenly reduced and excessive flow may occur. If the varnish has been applied too liberally, a large amount runs down in "tears" or "curtains," and a varnished cloth of irregular thickness results.

The flow of the applied varnish is controlled to some extent also by the rate of travel of the wet varnished cloth up the tower. The higher the speed of travel of the cloth through the varnish the greater the amount of varnish which is dragged up on the cloth. The viscosity of the impregnating varnish has, therefore, to be adjusted also in relation to the proofing speed.

Another factor which seriously interferes with flow is draughts. These may chill the applied varnish to an abnormal degree prior to its entry into the warm tower, and thus increase its viscosity and prevent normal flow. Draughts also cause flapping or vibration of the ascending cloth, which in turn impedes flow as evidenced by a waviness in the final surface of the insulating cloth.

It is obvious that the "pick-up" of varnish will be altered by pronounced temperature changes during application. If the temperature of the varnish in the trough alters, its viscosity alters simultaneously, and this in turn alters the thickness of the

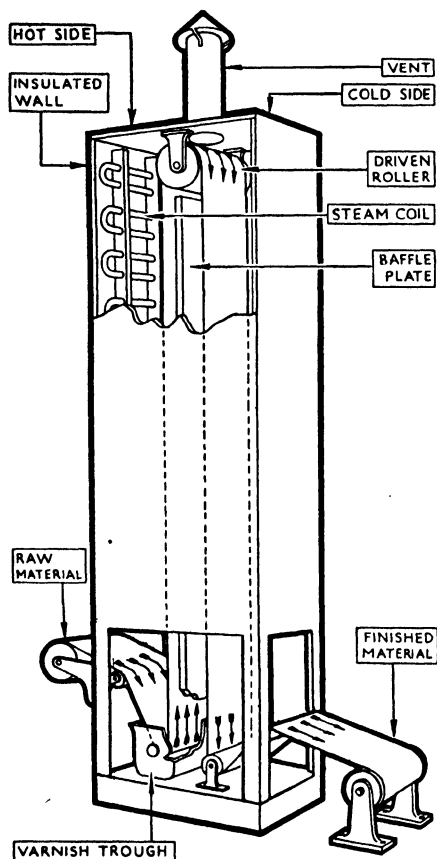


FIG. 23. Diagrammatic view of a drying tower for the production of varnished cloth.

applied film. If tower plants run continuously night and day, and the room or section which houses the troughs is fairly well isolated from cold draughts, the temperature of the varnish remains reasonably constant. It is only in a discontinuous process where the plants are started up afresh each morning and allowed to cool off overnight that violent temperature fluctuations are likely. The temperature of the varnish is low first thing in the morning and gradually increases during the day until it becomes approximately constant. In the morning, therefore, the "pick-up" tends to be higher than later in the day.

The heaters in the tower, as already indicated, are not placed immediately inside the closed-in portion of it, but generally a few feet from the bottom. This is to ensure that the

newly-coated ascending cloth enters into the hot zone gradually and not suddenly. The applied varnish is, therefore, warmed up slowly, and violent reductions of viscosity causing uncontrollable flow are avoided.

It is absolutely essential that the surface of the varnish in the trough is not disturbed during its application to the cloth. Any disturbance at the surface is reflected in a variation in thickness of applied varnish on the cloth. Nevertheless, it is necessary to replenish the trough from time to time as it becomes depleted. This must be done with extreme care. The most satisfactory way, adopted by some of the most efficient proofers, is to have a separate tank or reservoir which is "topped up" as required. Thorough mixing can be effected there without any danger of disturbing the contents of the trough itself, and the trough is replenished continuously by a supply of varnish pumped gently from the reservoir into the bottom of the trough. The varnish also overflows from the trough into the reservoir again so that there is a constant and gentle circulation of varnish. It is apparent also that if the volume of the reservoir is large, and the reservoir is kept near the trough so that the contents of both are maintained at the same temperature, then relatively small additions of fresh varnish to the reservoir will have practically no effect on the temperature of the whole system. Further, if sufficient varnish and thinners for one day's run are stored also on the same premises for twenty-four hours, to assume the same temperature as the contents of the trough, all risk of temperature variation is removed.

Other proofers add thinned varnish direct to the trough. If this procedure were conducted carefully there would still remain risks and limitations. It is essential to blend the new varnish with the old thoroughly, and this can be accomplished only by stirring, and stirring of necessity causes a disturbance of the surface of the varnish in the trough. If the plant is stopped while stirring is carried out there is a danger that overheating of the applied varnish, which is in the hot zone of the tower, will occur. If the new varnish were thinned to the same viscosity at the same temperature as the original varnish in the trough, its composition and characteristics would be different from the varnish left in the trough after the plant has been running for some time. Firstly, the varnish, as explained already, contains a thinner which is volatile, and under the prevailing warm conditions evaporation takes place, and the varnish gets progressively thicker. Secondly, varnishes are oxidisable materials and even in the form of a bulk of liquid some oxidation occurs. This causes changes in the characteristics of the varnish as evidenced by increase of viscosity. If oxidation occurs to a substantial degree the viscosity may

increase to the point of gelation. The new and the old varnishes, therefore, are liable to have vastly different characteristics, and for this reason they should be thoroughly blended. When the varnish is in constant circulation to and from a reservoir, changes due to oxidation, etc., are slight, because they are spread over a large volume of varnish, and the whole of the varnish is not exposed to the air all the time.

The viscosity of the varnish in the trough may change also because of the continual flow-back of varnish which has been applied to the cloth. The wet varnish on the cloth is in an ideal condition for evaporation and oxidation to occur, because it is exposed as a thin film over a large surface. This permits volatilisation and oxidation from both sides ; a process encouraged also by the elevated temperature near the base of the tower.

The surface of the varnish in the troughs is exposed, and in the course of time dirt, fluff, and other extraneous matter is collected. Loose nap or fibres on the cloth are also washed down into the trough to some extent by the excess varnish which flows back from the cloth. If the trough is left overnight or if the varnish contained therein is a rapid drying material, skinning of the varnish will occur. Often these skins cannot be removed easily, and they break up, disperse in small pieces into the varnish and contaminate it. Varnish containing extraneous matter produces a very bitty or rough insulating cloth.

The moral is, therefore, to keep the trough covered when not in use, or better still to empty it. In any case the trough should be cleaned out thoroughly at regular intervals to remove accumulated sediment. Again the constant circulation system is preferable because a filter can be included in the system, and this effectively removes extraneous matter as fast as it arrives.

The stoving times and temperatures in tower plants vary considerably. Temperatures may be as low as 170° F. or as high as 300° F. When low temperatures are used the stoving time has to be prolonged. At 170° F. the stoving time may be as long as two or three hours, but at 300° F. it may be reduced to twenty minutes. These times should only be regarded as approximate, because they vary according to the type of impregnating varnish used. In Great Britain most of the proofing is done within the temperature range 210°–280° F., with stoving times of from ninety to twenty-five minutes respectively. It should be borne in mind, however, that the stoving times given represent the actual times the impregnated fabric is inside the tower, and the tower is not

at the maximum temperature everywhere. The times in the heat, therefore, are often substantially less.

Textile supports which may be satisfactorily treated in towers are calendered cotton cloth, natural and artificial silks, and glass silks. All these materials are covered by the conditions outlined above.

When an adhesive insulating cloth is required, the process is modified, for normally only one surface of the cloth possesses adhesive properties. The proofed cloth is coated with a face coat of adhesive varnish on one side by means of a coating machine.

Adhesive varnishes differ from impregnating insulating varnishes in that with most types they are designed to dry by evaporation of the solvent only. Thus only relatively short stoving times and low temperatures are necessary to effect the evaporation of the solvent and to generate the adhesive properties. In fact, it is an advantage not to stove these varnishes more than necessary, because, like many compositions of an organic nature, they tend to oxidise and lose their adhesive properties. It is opportune here to point out that adhesive varnishes should be carefully checked for retention of adhesiveness, for it is an easy matter to formulate a varnish with good adhesive properties initially, but a difficult matter to formulate one with permanent adhesive properties.

Sometimes the coated cloth as it leaves the tower is subjected to an ageing or maturing process. This consists in exposing lengths of proofed cloth, in a large chamber, to free circulation of air. The operation is conducted either at ambient temperature or at a slightly elevated temperature. The process is really a safeguard against the possibility of spontaneous combustion during storage, but it is also an admission of deficiencies, either in the proofing conditions or in the formulation of the impregnating varnish.

Ageing or festooning, as it is sometimes called, is designed to finish off the drying process which should have been completed in the tower. A higher temperature in the tower or a larger run would have achieved the results desired. On the other hand, impregnating varnishes which, after reasonable stoving conditions do not require to be festooned subsequently, can be easily formulated. They are, of course, more expensive than varnishes which are substantially drying oil, but they possess many other advantages, in addition to the possibility of eliminating the ageing process.

When the varnished cloth is sold in the form of strip or tape, the rolls are passed through a slitter or guillotine, and cut into narrow rolls from which the tape is unwound as required.

CHAPTER VI

THE STORAGE OF TEXTILES, IMPREGNATING VARNISHES, AND VARNISHED CLOTHS

THE STORAGE OF TEXTILES

THE storage of textiles is an important matter. Most textile supports used for the production of varnished cloths can be ruined through faulty storage.

Cotton, natural silk and artificial silks, all suffer damage under the action of atmospheric and other influences. Asbestos cloth with glass silk can be regarded, by reason of their chemical structure, as substantially inert to ordinary external influences.

Deterioration of cotton, natural and artificial silks on storage, is brought about by one or more of the following agents—light, moisture, heat, mildew and certain chemical reagents, either present initially in the fabrics or there by accidental contamination. The disintegrating effect of some of these agents is encouraged to a dangerous degree by the presence of others.

The ideal storage conditions, therefore, are easily deduced, for they are exactly opposite in nature to disintegrating agents enumerated above. They are found in a dry, cool, shady, well-ventilated room. Mildew formation is also inhibited or reduced by the deliberate addition of special antiseptics to fabrics by the textile manufacturer, and chemical action by effective neutralisation and scouring.

The action of light on silk seems to be dependent on the pH of the aqueous extract obtained from it. Artificial silks and nylon both deteriorate on exposure to light.

The destructive action of heat alone, in the absence of other factors is not very serious at the temperatures prevailing in store-rooms. Months and even years of storage are necessary before any real reduction of strength occurs with cotton at temperatures 20° or 30° F. above ordinary atmospheric temperatures. As the temperature increases the tendering effect increases in proportion. Both moisture and oxygen combine to accentuate the disintegrating action of heat, and although the moisture concentration can be controlled if desired with advantage, it is not a practical proposition to attempt the control of oxygen concentration. Its disintegrating effect is recognised, and its relatively minor

influence under reasonable conditions need not cause undue alarm.

The destructive effect of heat depends in the main on the presence of chemicals in the fabrics, and since it is not always certain that they are absent, the cooler the storeroom the better. It is known, for example, that bleached fabrics deteriorate much more rapidly under warm conditions than unbleached and well-scoured fabrics, and this may be one of the reasons which has influenced some proofers to use unbleached textile supports for varnished cloths.

Textiles are very easily damaged by creases, etc., if mishandled, and care should be taken in storage to ensure that extra folds or creases are not caused. It has been explained already that creases cause imperfections in the flow of varnish when applied by the proofer, and once they have been introduced in the fabric, the only chance of complete removal is by ironing. Apart from the great inconvenience of this procedure, the application of a hot iron to cellulosic textiles, especially if they contain traces of certain chemicals, may be disastrous in its results. The heated area of textile may be tendered considerably.

THE STORAGE OF IMPREGNATING VARNISHES

Impregnating varnish is supplied in steel drums or wooden barrels of 40 gallons capacity, or in 5-10 gallon metal containers, direct from the varnish manufacturer. Thinners, which normally consist of petroleum distillate, are usually bought in bulk either from a petroleum company or from a distiller. It is only for complex synthetic varnishes that the proofer buys thinners from the varnish manufacturer.

The storing of thinners is simpler than that of varnishes, and will be dealt with first. The main point to consider is the fire risk, for all thinners used are more or less inflammable. The flash-points of the common thinners are given in the table on p. 82.

Loss of thinners by evaporation may reach costly proportions, particularly with thinners like benzine, petrol and toluol, but it can be minimised by employing very tightly fitting closures and keeping them secure. Considerable losses by evaporation with volatile thinners like these occur from 5 and 10-gallon containers which to all outward appearances are securely sealed. Losses by evaporation during storage of the other thinners listed above are not usually of a high order, but all thinners whether very volatile or not, if delivered by a cock or tap, seep away to waste in

Table 18

Flash Points of Thinners for Impregnating Varnishes

Thinner	Normal Flash Point or Range (° F.)
1. Paraffin	120-130
2. Heavy naphtha	100-120
3. Distillate	95-115
4. White spirit	90-100
5. Xylol	75-80
6. Light solvent naphtha	70
7. Benzine, petrol	60 or below
8. Toluol	45-55

substantial amounts if the seatings are not perfect. The installation of underground storage tanks does much to reduce losses by leakage, and the risk of a major conflagration from a nearby small fire is also lessened.

A word of caution in opening drums of volatile thinners is not amiss. If perchance they have been left exposed to the sun in an open yard, or recently rolled vigorously in a half-filled condition, a high pressure of vapour may be built up inside them. The man who unscrews the plug will stand a good chance of receiving the full force of the compressed vapour in his face unless great caution is observed. This precaution is, of course, equally necessary in handling impregnating varnishes also, for they may contain similar volatile thinners, and are likewise delivered in airtight containers.

Thinners of the types enumerated do not deteriorate in quality during storage, but this is not by any means true of impregnating varnishes. Wrong conditions of storage may cause endless trouble. Varnishes need, before all else, temperate storage conditions; they are damaged by both abnormally high and by low temperatures. The ideal storage temperature for a varnish is about 60° F., and 10 degrees either way will not cause serious trouble. There is really nothing difficult in providing storage conditions with a temperature around 60° F., for this is the usual indoor temperature of any factory. It is surprising, however, how often drums of varnish are left in open yards, exposed to all the elements, not excluding temperatures substantially below freezing point.

If a varnish is constantly maintained at temperatures greatly in excess of 70° F. by reason of exposure to the summer sun or because of proximity to boilers, furnaces or hot-water pipes, a number of troubles may develop. Firstly, there is the possibility of pronounced viscosity increases, as the result of either stimulated evaporation of thinners, or further polymerisation or oxidation of the varnish constituents. Varnishes initially in a state of high polymerisation, can quite easily gel completely, and once this condition is reached, regeneration is impossible, and the varnish is useless.

Varnishes should never be stored for long periods in half-empty containers, for skinning at the surface is sure to occur with most types of varnish. It is unreasonable to expect otherwise. Storage at high temperature accentuates the skinning tendency, simply by reason of the higher temperature, but if a viscosity increase occurs also, there is an even greater chance of skin formation. The removal of skin means loss of valuable varnish, and this is often quite substantial because much liquid varnish is likely to be removed with the skin also.

Low temperatures, especially near the freezing point, may throw the varnish out of balance completely. Loss of homogeneity in the varnish is evidenced by slight or gross precipitation of one or more of the ingredients. Lead driers particularly, and manganese driers under severe conditions, are likely to be deposited from the varnish, and their removal may lead to poor drying properties of the varnish when applied on textiles, or to drying irregularities, wherein the resultant films are badly wrinkled and ravelled. Lead compounds are driers, used in combination with more powerful driers, to modify surface drying tendencies—their removal from the sphere of action upsets this intention.

Waxes and other lubricants are common minor constituents of impregnating varnishes, and generally their solubility is poor. Varnishes containing these lubricants are very sensitive to low temperatures, and it is by no means certain that the bulk of such constituents will not be crystallised from solution completely. Mere loss of these constituents from a varnish by precipitation is not in itself a major catastrophe. The remaining varnish is not useless—it can be consumed, but its properties will be somewhat impaired. It is not so much the loss of these lubricants which matters, but the harmful effects which the solid crystals dispersed throughout the varnish cause. The solid particles are carried up on to the varnished cloth as it ascends the tower and as soon as

they meet the heat they melt. In melting they make the varnish flow away from the cloth and leave bare patches or pinholes.

If resin or other constituents are deposited from a varnish through chilling it is extremely serious, for nearly always the varnish is useless and nothing can be done with it. When, however, a varnish is out of condition by reason of drier or lubricant separation, it can be regenerated often into its original uniform condition by careful warming. If the separated material were lubricant, regeneration is certain; warming cannot, however, always affect solution of precipitated drier.

The method of regenerating a chilled varnish is to stir it thoroughly to ensure complete uniformity of its separated ingredients, then to warm the whole to a temperature of 60°–80° C. for an hour or so. Obviously great care must be taken during this operation for such temperatures increase volatilisation of the varnish thinners considerably, and they will be much above their flash-points. The heating process must be conducted, therefore, remote from naked flames.

Varnishes as delivered to the proofer should be clear and free from all matter in suspension, and this condition is achieved by filtration or centrifuging. Nevertheless, in spite of this, and the fact that the varnishes may have been filled into new and inspected containers, some small amount of dirt is almost certain to find its way into the varnish. Before using impregnating varnishes, therefore, it is a wise precaution to run them through fine muslin or even 180–240 mesh gauze. Some slight skinning is likely to take place also in all but completely filled containers, and straining is effective in removing skins simultaneously.

It is a good plan, if large quantities of impregnating varnish are used, to store them in large storage tanks of a thousand gallons capacity or more. Two storage tanks for each type of varnish are the ideal arrangement, for one can be left to settle and stabilise itself undisturbed, whilst fresh deliveries of varnish can be pumped into the other.

If the tank is fitted with drawing-off cocks at various levels the varnish can be drawn off first from the high level cock and then from those at lower levels. The bulk of the varnish, from which dirt has settled, is undisturbed by withdrawals at the top, and the varnish withdrawn is clean and free from all dirt and suspended matter. Before transferring it to the dipping trough of the tower it is only necessary to run it through coarse scrim or gauze to catch pieces of skin. Considerable time is saved thereby, for

straining through fine muslin or gauze is apt to be a tedious process.

Impregnating varnishes are rarely bought ready for use ; they are thinned by the proofer as required. It is a very great advantage to transfer the varnish to a bulk storage tank fitted with an agitator, and to thin it to the working viscosity or density *in situ*. After mixing, the thinned varnish is left to settle, and clean varnish ready for immediate transference to the dipping trough can be run off as required. The lower viscosity and density of the thinned varnish greatly facilitate settlement of extraneous matter, and the conversion of a large volume of varnish into a condition ready for use in one operation, means that the time spent in the thinning of a number of small lots of varnish, as required to replenish the troughs, is saved.

Thinned varnishes tend to skin over much less than varnishes at normal viscosity, so that less trouble in this respect will be experienced if the above procedure is adopted. If a varnish is very prone to skin, the air above the surface can be replaced by carbon dioxide, or even furnace gases which are renewed occasionally.

THE STORAGE OF VARNISHED CLOTHS

Varnished cloths, composed as they are of organic materials, are not chemically inert. They are in a constant state of gradual change and decay. Ultimately, given sufficient time, they become useless as electrical insulators.

Although in the process of manufacture varnished cloths are brought to as complete a state of "dryness" as possible, because dryness is associated with the acquisition of other valuable properties, the drying process is rarely absolutely complete, or, if it is regarded as complete, then the resultant film is not chemically inert. Even materials which are commonly recognised as being very inert, continue to undergo appreciable oxidation. As most impregnating varnishes are formulated in some measure on vegetable drying oils or their constituent unsaturated acids, considerable oxidation is likely to occur in storage, even with apparently dry varnished cloths. This cannot be prevented, because it is impractical to store varnished cloth in a perfect vacuum.

Storage at high temperatures and, in fact, at any temperature, assists a continuation of the oxidation process, and the higher the storage temperature the greater the oxidation. One of the

first signs of increased oxidation is loss of flexibility. In severe cases a varnished cloth may become hard and brittle. By a similar process of oxidation on storage adhesive tapes and cloths tend to lose their adhesiveness. The first point then, in order to minimise embrittlement on storage or loss of adhesive properties, is the maintenance of a low temperature.

Fortunately the form in which varnished cloth is stored, as tight rolls or as layers of sheets, restricts the amount of oxidation. The only freely available atmospheric oxygen for attack is that which is entrapped in the narrow spaces between adjacent layers of cloth, except, of course, at the edges of the roll or pile which are in contact with unlimited supplies of air. The extent of the oxidation under these circumstances is limited, hence embrittlement also between layers of cloth remote from edges. At the edges there will be a tendency to embrittlement of ordinary varnished cloths and a loss of adhesive properties with adhesive cloths and tapes. To avoid embrittlement and loss of adhesive properties, therefore, it is an advantage to exclude air as much as possible by keeping cloths and tapes in roll form or in thick layers of sheets.

If a varnish is dried incompletely on cloth or silk the greater the chance of subsequent oxidation, when the necessary conditions are supplied. If a varnished cloth therefore, were rolled by the proofer straight from the tower in a semi-dried condition, its drying process may continue subsequently with disastrous results. The phenomenon of spontaneous combustion may occur, and this means that the oxidation of the varnish film proceeds at such a rate that the heat generated in the process cannot be dissipated quickly enough. The temperature rises, and since most varnish films and textile supports are combustible materials they char, and in some cases may actually ignite spontaneously. The tendency to "heating up" or to spontaneous combustion of a varnished cloth, can be checked experimentally, and details of the method are given in Chapter IX.

If a varnished cloth ignites spontaneously it is the fault either of the varnish manufacturer, because of faulty formulation or manufacture of the varnish, or of the proofer because he has curtailed the drying process. But the user of varnished cloth can himself minimise the tendency to spontaneous combustion by arranging for correct storage conditions. Since spontaneous combustion is caused by the accumulation of heat at a given spot, it is obvious that storage conditions should be as cool as possible

to assist in its dispersion. Low temperatures of storage also reduce the tendency to oxidation and consequent heat generation.

For combustion or oxidation to take place a supply of oxygen is necessary.

Sometimes there is enough air between the interleaves of varnished cloth for this, and charring proceeds while the varnished cloth is still in roll form or in packed sheets as delivered from the proofer. At other times it occurs when a partly dried roll is unrolled or when packed sheets are disturbed. A new supply of air is made available in both instances. When the roll is re-rolled and the sheets re-stacked, especially if pressed together tightly, combustion may occur.

Spontaneous combustion with varnished cloths for electrical purposes is not a common occurrence, for the varnish is usually dried well at a high temperature. It is, however, a phenomenon against which to guard.

Overheating of varnished cloth reduces its strength, and cloth which has "heated up" or scorched, is very tender and weak in the area affected.

The first stage in the oxidation of varnished cloth is a hardening or embrittlement. Frequently a condition of maximum hardness is reached, and then, with the combined influence of heat and moisture, the varnish film disintegrates and gradually becomes softer; if the conditions are severe enough the film liquefies completely and the degradation products rot the cloth. Varnish films which develop a stickiness or which liquefy on storage are said to have "come back."

The most adverse circumstances to bring about this result are high temperature and humidity, and tightly-packed cloth. If a user wishes to store varnished cloth under tropical or semi-tropical conditions he should first ascertain that the cloth has been specially designed to accommodate them, and then store the rolls separately in cool well-ventilated racks. Tight rolls or packed sheets deteriorate much more quickly under tropical conditions than varnished cloth which is festooned with free circulation of air. The resistance to this form of deterioration can be deduced from an accelerated ageing test and the method of conducting it is described in Chapter IX

CHAPTER VII

THE PROPERTIES OF VARNISHED CLOTHS

Colour

VARNISHED cloths of all types are available chiefly in two colours—yellow and black. The yellow cloth varies somewhat in shade, for it nearly always relies for its colour on the natural colour of the impregnating varnish. The impregnating varnish is always dried by heating, and since heating causes yellow impregnating varnishes to discolour or “yellow” to varying extents, it is obvious that the final shades of yellow obtained will differ considerably. Normally, too, the higher the drying temperature the deeper the colour of the varnished cloth.

Yellow varnished cloth is not necessarily a rich bright yellow colour; it may be any colour from this to a rich brown.

For some reason cloths which are a rich golden brown are preferred to those which may be only an anæmic straw colour. Neither important electrical nor mechanical properties of an insulating cloth are governed in any way by colour. Often the pale straw cloth is much superior to the rich golden brown one from an electrical insulating point of view, and after all, in materials such as these it is the electrical properties which are the most important.

It would be a real step forward if users considered the pros and cons a little more before insisting on a rich golden brown insulating cloth, for many new synthetic resins with outstanding electrical properties are almost without colour. If the impregnating varnish formulator wishes to exploit their valuable properties and still satisfy a user on the question of colour, he has to resort to the doubtful addition to the varnish of colouring matter—dyestuff or pigment—both of which are liable to affect adversely other important properties.

Yellow varnished cloth is sometimes described as “clear,” and this designation distinguishes it from the black variety which is quite opaque.

The clearness or transparency of yellow varnished cloth varies considerably with the textile support used. The most opaque variety of yellow cloth is that which is produced from white, heavily starched, calendered cotton, and its opacity is due, in the

main, to the fact that the starch or other size, present as a fairly continuous film, prevents thorough penetration of the impregnating varnish into the cotton threads.

Sometimes yellow cloths exhibit numbers of small opaque patches on a background of general transparency. This is due to irregular absorption of the varnish by the cotton.

Natural silk, glass silk, nylon and most rayons, when proofed and converted into insulating cloths, give almost completely transparent films.

If insulating silks with distinctive colours are required, these are obtained by applying a clear impregnating varnish over dyed fabric.

Black varnished cloths are nearly always made by applying a black impregnating varnish to undyed fabric. The blackness and opacity of these cloths is provided solely by the varnish itself, except in rare instances when, in order to improve opacity, a black varnish is applied over a black dyed cloth. By reflected light black varnished cloths look quite opaque, but if they are viewed against a strong transmitted light it will be seen that they are a transparent dark brown. The intensity of the colour of black cloths varies considerably; some appear a deep rich black, others are greyish or brownish by comparison. Cloths which are a rich black colour are most favoured. Again, however, it must be remembered that opacity is not necessarily an infallible guide to quality.

Yellow and black varnished cloths differ appreciably in properties, and this is understandable because the constituents in the two types of insulating varnish involved, differ widely. The difference in properties of yellow and black cloths is directly attributable to the presence of natural asphaltum or petroleum bitumen in the varnish for the latter.

The asphaltums or bitumens are incorporated because they provide blackness and opacity, but they cause also other marked differences in properties. The incorporation of asphaltum or bitumen in a varnish, whether of the air drying or stoving variety, produces inhibition of the normal drying process. For this reason black cloths are generally, but not always, more flexible than yellow cloths, and have inferior oil resistance.

Because of the chemical inertness of asphaltums and bitumens, they confer, in part, some of this property on the black varnishes made from them, and for this reason black varnished cloths often possess better chemical resistance than yellow cloths.

Notes included in B.S. Specification No. 419—1981, state that “the black material is also rather more water repellent and has slightly higher electric strength.” Whilst this statement may have been true in 1981, it should not be regarded as strictly correct to-day.

The properties of both black and yellow varnished cloths have improved considerably since then, and it is by no means uncommon to encounter yellow cloths with substantially better water resistance, and dielectric strength, than those of the average black cloth.

Most of the yellow impregnating varnishes are based on some form of synthetic resin, and asphaltums and bitumens are not always readily compatible with them to convert them into black varnishes. With certain types of synthetic resin it is quite impossible to incorporate asphaltum. In black impregnating varnishes, therefore, the extent to which the valuable properties of synthetic resins can be exploited is limited. In yellow varnishes, on the other hand, there is no such limitation, for no asphaltum-like material enters into their composition.

Thickness

The thickness of varnished cloth is of greater importance than might be supposed at first thought, for it has an influence on the design and construction of all manner of electrical machinery. Often the designer of electrical machinery has yearned for extra dimensions with which to fit in the insulation necessary for high efficiency. Obviously, thickness is an essential feature of any insulator and the designer has been forced to compromise. This compromise has resulted in a measure known as the space factor.

In order to appreciate the importance of the thickness of varnished cloth, it is advisable in the first instance to understand just what the space factor really is.

The space factor may be defined as the ratio of the total cross-sectional area of the conductors in a given winding, to the cross-sectional area of the window in which that winding fits.

For a given output in an electrical machine the ratio of the volume of copper, as used for the windings, to the volume of iron, in the form of the magnetic core, should be maintained as close to the optimum volume as possible. Factors such as mechanical strength, cooling, etc., will, of course, have to be considered and allowances made for them.

If the whole of the window space were filled with metal con-

ductors, the ideal conditions would be achieved and a space factor of unity obtained. It will be seen at once, however, that this condition is impossible. It is impossible for several reasons, among which may be included the facts that the conductors must be insulated and that their usual and most convenient shape is cylindrical. Their cylindrical shape means that voids must occur between the boundaries of adjacent wires.

The space factor can be improved by several means. A good deal can be achieved by careful special arrangement of the conductors in a given area. This is made clearer by examining the case of an armature winding, where, by cutting down the number of slots, and thus increasing the number of conductors per slot, the space factor is improved.

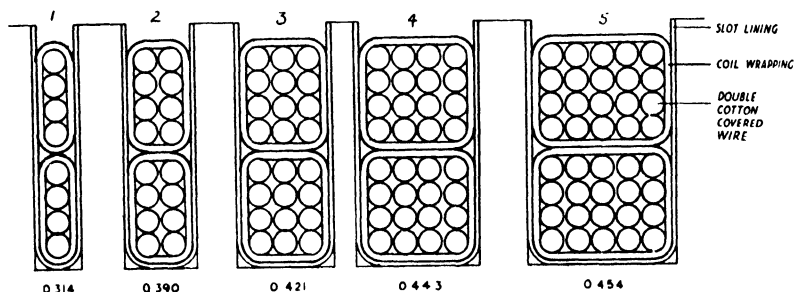


FIG. 24. Method of improving the space factor. (Armature slots.)

The diagram above represents armature slots containing respectively 1, 2, 3, 4 and 5 commutator segments per slot; each segment is wound with four turns of wire. In the simplest case of one slot per commutator segment there would be eight wires per slot. This elemental slot is shown on the left-hand side of the diagram.

The corresponding space factors are 0.314, 0.390, 0.421, 0.443 and 0.454, and it is at once seen how the space factor increases as the number of slots decreases, for the same depth of slot.

The space factor can also be improved by altering the shape of the conductor from cylindrical to rectangular.

Thirdly it may be increased by reducing the thickness of the insulation. This is possible in two ways, firstly by using thinner coverings on the conductors themselves, and secondly by using thinner coil wrapping materials. It is in this latter instance that the thickness of varnished cloths is important. Reference to the diagram demonstrates clearly, that if the coil wrapping in the form of varnished cloths were reduced in thickness, or preferably

eliminated altogether, the ratio of cross-sectional area of conductor to cross-sectional area of window must increase.

The same argument applies to all coils met with in practice, such as field coils, transformer windings, choke coils, etc., as the efficiency of a coil depends upon whether the maximum number of ampere turns has been put into the available space.

The diagram on p. 93 illustrates the use of varnished cloth as an insulator between windings in a small transformer such as is employed for supplying power to a modern radio or television receiver. It actually shows not one, but four separate windings, wound on the centre limb of the iron stack, and at least three places where varnished cloth can be used as the insulating material, namely, between H.T. and PRI windings; between L.T. and PRI windings, and between the L.T. windings.

Again, the winding space is rigidly limited by the window in the iron stack, and the designer's problem is to get the maximum number of ampere turns for each winding into the window, and, at the same time, include sufficient insulation to protect the windings from breakdown. Adequate insulation is especially important when there is a likelihood of up to 1,000 volts between a high-tension winding and the rectifier heater. The selection of the best insulating material is of prime importance, but, of course, in mass produced components cost is a major factor and cheaper and less efficient insulating materials may be used.

The thickness of the unimpregnated textile supports for varnished cloths varies appreciably as the dimensions in Table 23 show, and the initial thickness of the raw textile influences the final thickness of the varnished cloth. Ordinary calendered cotton cloth which forms the basis of varnished cloth has a thickness, in the unimpregnated state, of approximately 5 mils; fine natural silk, on the other hand, is only about 1.6 mils thick. Gampi tissue paper, probably the thinnest material obtainable, is less than 1.0 mil thick. After treatment with two coats of impregnating insulating varnish, the calendered cotton cloth becomes 6.7 mils thick and the natural silk about 8.5 mils thick. Since the dielectric strength of varnished cotton is only about one-half of that of varnished natural silk, it is concluded from a consideration of space factor that varnished natural silk is preferable to varnished cotton. Further information on the relative thicknesses of various varnished textiles to give a standard overall breakdown voltage is given in Table 25.

The thinnest asbestos cloth obtainable in Great Britain is about

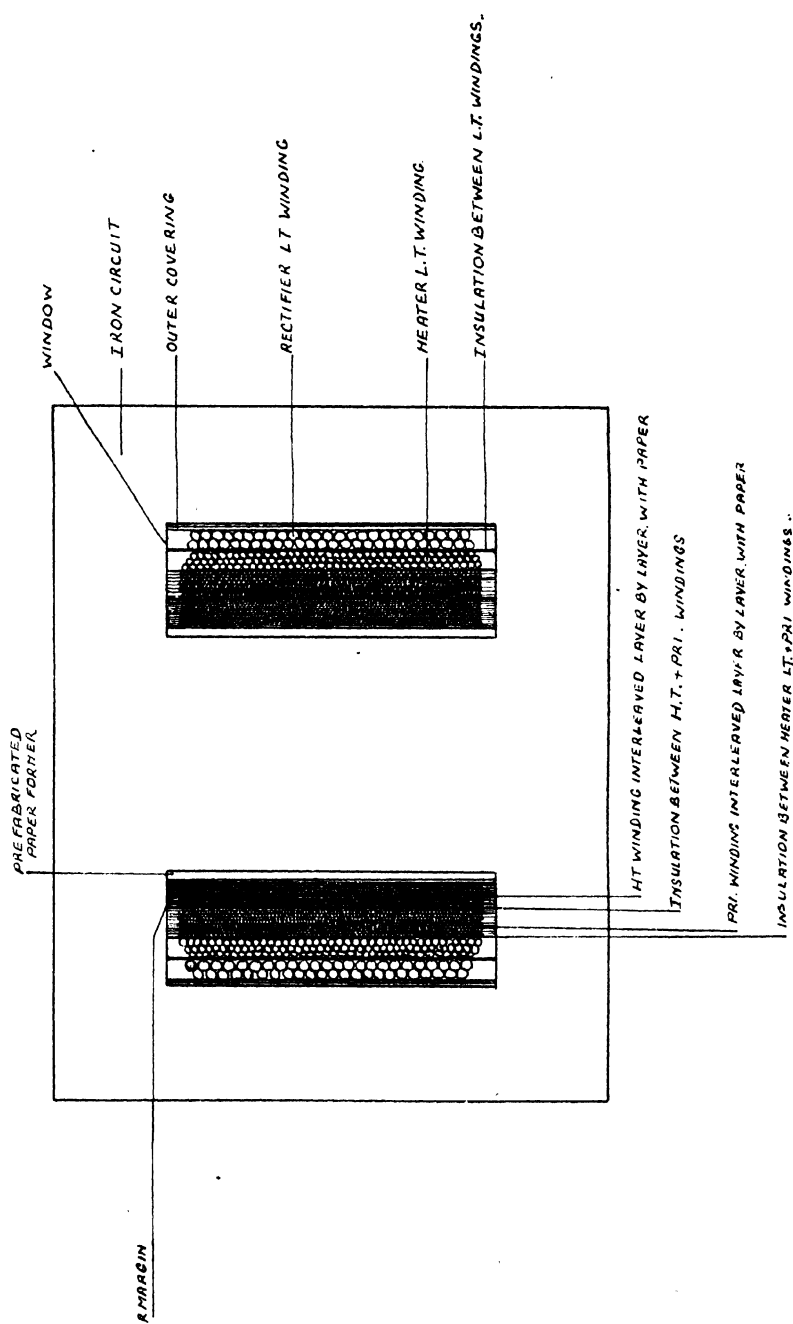


Fig. 25. Section through a small transformer showing location of insulating materials.

16 mils thick in the unimpregnated condition. After treatment with impregnating varnish to fill its interstices and to give a smooth even film it would be substantially thicker. Its excessive thickness by comparison with that of other textile supports has limited its use as a suitable base cloth.

Both asbestos cloth and glass silk fabric are competitors for use in components operating at high temperatures. According to Robertson (18), 5-mil glass tape has, to an appreciable extent, replaced 10-mil asbestos tape for slot cell insulation. The decrease in insulation thickness gives an improvement in heat conductivity, which means better dissipation of heat from the copper to iron. It is also claimed to be preferable to use a half-lapped layer of 5-mil glass tape instead of a butt-lapped single thickness of asbestos, if 10-mil insulation is desired.

What is the thickness of a piece of varnished cloth? Varnished cloth cannot be purchased at an exact specified thickness, for this measurement varies perceptibly. Users, however, refer to the thickness of varnished cloth in round figures, *e.g.*, 5, 7, 10 mil, etc. It is almost impossible to reproduce varnished cloth of absolutely uniform thickness, and most specifications, appreciating manufacturing difficulties, permit certain tolerances. For example, B.S.S. 419—1931 indicates the following permissible tolerances :—

Table 19

Normal Thickness (mils.)	Tolerances (Per cent.)
5	— 0 + 20
7	— 10 + 10
10	— 10 + 10

Many factors militate against the production of varnished cloth of a uniform thickness, but proofers, nevertheless, nearly always produce highly satisfactory products within agreed limits. The modifying factors with which they have to contend include :—

1. Variation in thickness of the base textile.
2. Variation in composition or manufacturing treatment of successive batches of varnish.
3. Changes in viscosity of the varnish during application, as the result of temperature changes, evaporation, etc.
4. Variation in speed of coating process.

5. Irregularities in the movement of the coated cloth during the drying process, caused by flapping, etc.

6. Careless additions of fresh varnish to the dipping trough, which produce surface disturbances of the liquid impregnating varnish.

7. Presence of extraneous matter on the cloth or in the varnish.

8. Flow characteristics of the impregnating varnish.

But whatever precautions textile, varnish manufacturer, and proofer take, the resultant varnished cloth is not always of uniform thickness throughout the piece, for all thicknesses of varnished cloth. The uniformity of thickness depends upon the number of coats of varnish which have been applied. The first coat of varnish differs from its successors in that it has to perform the dual function of thoroughly impregnating every individual thread, and then, with any surplus, assist in building up a smooth film surface. Once-run cloths therefore usually look "starved," and it is not always certain that every interstice between warp and weft threads will be effectively filled. There is always the danger of pinholes. A cross-sectional view, moreover, of once-run cloth looks in miniature form like the parallel furrows of a ploughed field. In measuring thickness, the micrometer screw gauge only contacts the tops of the ridges, and the thickness recorded is substantially in excess of the true average thickness of the cloth. Since the total breakdown voltage of a specimen of varnished cloth depends upon the thickness of the material, it is apparent that the breakdown voltage at the bottom of a trough is much less than the breakdown voltage at the top of a ridge.

It is not improbable that a tiny protrusion or fault on a conductor would coincide with one of the troughs, and if there is not an adequate margin of safety, electrical breakdown is liable to occur at this point.

Often black impregnating varnishes have different flow properties from those of the yellow variety, and this is particularly noticeable with one-run calendered cloth. Black varnishes are very apt to flow down the cloth in a series of lengthwise tears, and because of the strong contrast between the black or dark brown colour of the varnish and the whiteness of the cloth, the variations in film thickness caused by these tears is most apparent. Careful formulation of the varnish can, however, minimise this tendency and assist in uniformity. As more coats of varnish are applied, variations caused by tear formation become less marked.

The unevenness of once-run cloth is much more obvious with

thick textile supports like calendered cotton than with fine natural silk. It is possible, by careful proofing procedure, to obtain a tolerably smooth film on silk with one fairly heavy coat of varnish, but it is very difficult, if not impossible, to achieve this result on cotton. It might be thought that a single coat of varnish of much increased thickness would remedy the trouble, but this in practice is not so, for there is a limit to the thickness of varnish coating which can be applied without causing other equally serious film defects.

Varnished cloths of commercially uniform thickness are obtained by applying two or more coats of varnish and, of course, if higher overall breakdown voltages are required, the thickness of the varnished cloth is increased by increasing the number of coatings. After two or three coats of varnish have been applied, irregularities of thickness become more the responsibility of the proofer. The photomicrographs represented by Figs. 26 and 27, show how the irregularities in film thickness diminish with an increase in the number of coats of varnish. They also show the differences between calendered cotton and natural silk similarly treated with several coats of the same varnish.

Dielectric Strength

Dielectric strength masquerades under other names. It is known variously also as the electric strength, breakdown voltage (B.D.V.), or puncture voltage. It is measured by the total number of volts required to cause a complete breakdown in an insulating layer, divided by the thickness of the specimen. Thus the dielectric strength is recorded as the volts per mil (*i.e.*, per 1/1,000 inch), or the kilovolts per millimetre. In Great Britain the former units are the more popular.

It is worth remembering that the voltmeter used to determine the breakdown voltage will be recording R.M.S. values, so that the crest voltage causing breakdown will be about 1.45 times this figure.* Thus when it is reported that a certain varnished cloth has a dielectric strength of 1,000 volts per mil, it really has a dielectric strength of 1,450 volts per mil calculated on crest figures. It is customary, however, to record dielectric strength on R.M.S. voltages.

The dielectric strength of the varnished cloth is often taken as the chief indication of its insulating properties, but to avoid confusion it is perhaps opportune to clarify the difference between dielectric strength and insulation resistance. Insulation resistance, briefly, is a measure of the resistance which an insulator

* For accurate work the crest voltage is taken as $\sqrt{2} \times \text{R.M.S. value}$.

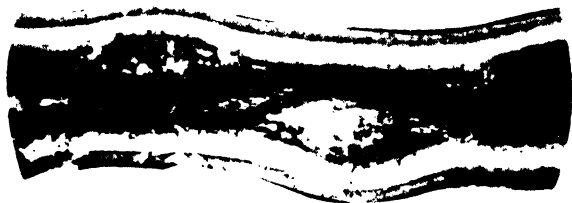


FIG. 26. Varnished calendered cotton cloth. (Magn. 90 dias.)



FIG. 27. Varnished natural silk. (Magn. 90 dias.)

Both photomicrographs are the same magnification ($\times 90$ dias.). Four coats of varnish were applied in each case, by dipping, and in order to distinguish the successive coats they were deliberately coloured orange and green alternately. The photographs were taken with polarised light and open nicols. The unevenness of the result with cotton by comparison with that of silk is striking.

exerts against the passage of an electric current. Dielectric strength is a measure of the property of resistance to the disruptive action of an increasing electric stress.

The dielectric strength of an insulating cloth is really the combined dielectric strength of its many components. It is the impregnating varnish which has the greatest insulation value; the silk, cotton or glass, etc., are merely present as supports to provide the mechanical strength to the weak varnish films.

In a piece of insulating cloth based on calendered cotton cloth there is a very complex conglomeration of components. Firstly, there is the cotton, comprising its many hollow tubular fibres, which may or may not be thoroughly impregnated with non-volatile varnish constituents. In the event of incomplete impregnation, which is frequently the case, the support consists of a combination of cotton and air. The cotton will possibly contain traces of size which may again be complicated mixtures of many components, none of which have any claims to be regarded as electrical insulators. Calendered cloth for impregnation, as explained already, is heavily starched in order to provide a smooth surface. Starch, therefore, on a basis of volume consideration, is an important part of an insulating fabric. Finally, there is the impregnating varnish—another composite material—which usually varies in itself, from its tough outer skin to its softer sub-layers, and which varies also according to its method of treatment before and during application, and according to its age and the conditions of ageing. Other impregnated textiles have somewhat similar and equally bewildering structures.

When the presence of so many undesirable constituents in the textile supports is first realised, it is a wonder that they provide anything of value electrically; and when variations which are associated with impregnating varnishes are added, it seems conclusive that no varnished cloths for electrical insulation of reasonable or constant quality could be obtained. The fact remains that varnished cloths which satisfy electrical requirements generally, are produced in great volume.

Why does an insulator such as varnished cloth break down when it is subjected to an electric stress of sufficient magnitude?

Actual breakdown is preceded by a sudden drop in resistance, and irreparable damage is done to the insulator.

When an increasing electric stress is applied, there is no doubt that considerable energy is evolved, which manifests itself as

heat ; and since this cannot be easily dissipated it concentrates at a given spot, and combustion begins. Where a breakdown in the insulation occurs there is often strong evidence of burning at the puncture. In fact, the area near the puncture is generally blackened and charred, and the hole itself is evidence that the material has been burned completely away. Incombustible inorganic materials may fuse or volatilise.

If the insulator is a good conductor of heat, in which case it is usually a poor electrical insulator, then any heat developed prior to actual breakdown may be conducted away almost as quickly as it is generated. If, however, its heat conductivity is poor the temperature will rise. This in turn will cause a reduction both in dielectric strength and insulation resistance. More current will be permitted to pass, and this in turn will cause more heating. The process is cumulative and ultimately complete breakdown occurs.

The actual size of the puncture varies with the heat resisting properties of the insulator. Varnished cloths formulated as they are from organic materials, have comparatively poor resistance to disintegration by heat, and often provide punctures a millimetre or two in diameter. Glass and silica sheets, on the other hand, are inorganic materials with a high order of heat resistance, and in both cases the puncture is so fine as to be almost undetectable (1). The presence of moisture also tends to reduce the size of the puncture (2).

Photomicrographs as represented by Figs. 28-33, indicate various forms of puncture in natural silk, cellulose acetate, nylon, calendered cotton, glass silk, and Gampi tissue paper. All these supports were impregnated with the same varnish.

Each of the photomicrographs shows strong evidence of carbonisation at the puncture. With some varnished cloths the formation of the puncture is so violent as to constitute a minor explosion. Microscopical examination of the puncture in varnished natural silk shows evidence of this, in the number of loose particles of carbon distributed around the smooth-edged hole.

Punctures in impregnated glass fabric are characteristic. The hole has a very irregular shape, just like a hole in a rush-work basket. It is easy to distinguish the various stages of the degradation. The varnish film first turns brown, then it chars, and is ultimately burned cleanly away from the individual glass filaments. These then collapse and melt, because of the heat involved, and form globules of molten glass.

HIGH-VOLTAGE PUNCTURES IN:



FIG. 28. Varnished gampi tissue paper. (Magn. 75 dias.)



HIGH-VOLTAGE PUNCTURES IN:

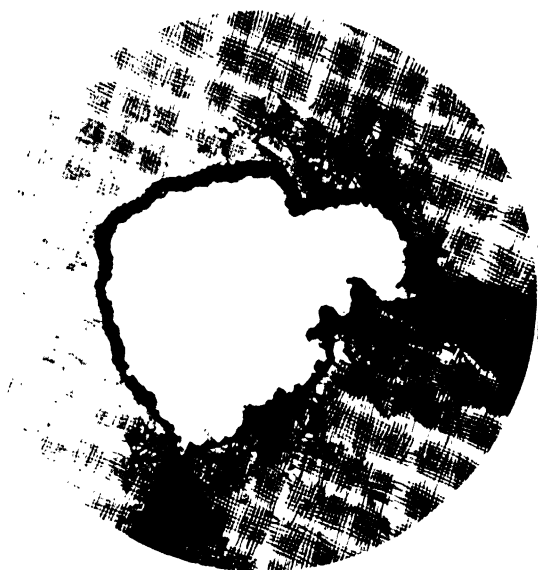


FIG. 30. Varnished nylon. (Magn. 40 dias.)



The Gampi tissue paper has a rather smooth-edged hole, and because of the absence of woven threads, there are no **ragged** protrusions. The tiny particles of carbon distributed around the hole suggests very violent burning or a minor explosion.

A nylon puncture resembles that in tissue paper, but the edge of the burn is less regular. Viscose also gives a comparatively smooth puncture. A puncture in varnished cellulose acetate is similar to that in glass fabric, in that appreciable melting occurs. There is, however, no sign of varnish being burned cleanly from the fabric threads; the impregnated fabric is burned away completely—both varnish and cellulose acetate—just as if it were eaten away in overlapping mouthfuls.

Because of the large amount of varnish on calendered cotton the varnish film near the hole softens, swells and bubbles. Hundreds of fissures are usually plainly visible around a somewhat rough hole.

For further information on the nature of breakdown and the mechanical, electrical and thermal effects, the reader is referred to "Dielectric Phenomena," Vol. III., by Whitehead.

The conditions prevailing at the time of the dielectric strength determination, and the method of the determination are of fundamental importance, for they affect the final result considerably.

The Effect of Frequency. Dielectric strength is determined by the employment of an alternating current, and the frequency of the alternation is important. The higher the frequency the lower the voltage required for breakdown. To be more precise, breakdown voltage decreases logarithmically with frequency.

The effect of frequency upon the breakdown voltage has been determined by several workers, including Montsinger (3), Vogel (4) and Dieterle (5). This is included in the following table, but the results of Montsinger are perhaps the most important for those interested in insulating cloths, because they were obtained from oil-treated pressboard. This is a near relative of varnished cloth, but Dieterle used mica.

Because of these variations, a standard frequency is specified—usually 50 cycles per second—and the alternating voltage should be approximately sinusoidal.

Obviously it is useless to determine dielectric strength with D.C., for its disruptive effect upon insulators is much less than that of A.C. Breakdown voltages with D.C. are, according to many workers, 33 per cent. or more higher than with A.C.

Table 20
Variation of Breakdown Voltage with Frequency

Worker	Conditions of Test	Duration of Applied Voltage (secs.)	Frequency (c.p.s.)	B.D.V. in K.V.
Montsinger	Oil treated press-board in oil at : (a) 100° C.	$\left\{ \begin{array}{l} 0 \\ 0 \\ 0 \end{array} \right.$	$\begin{array}{c} 60 \\ 200 \\ 420 \end{array}$	<i>approx.</i> 140 (R.M.S.) 120 (R.M.S.) 60 (R.M.S.)
	(b) 25° C.	$\left\{ \begin{array}{l} 10 \\ 20 \end{array} \right.$	$\begin{array}{c} 60 \\ 200 \end{array}$	65 (R.M.S.) 56 (R.M.S.)
Vogel	—	$\left\{ \begin{array}{l} 200 \\ 200 \\ 200 \\ 200 \end{array} \right.$	$\begin{array}{c} 60 \\ 140 \\ 220 \\ 350 \end{array}$	44 (Eff.) 40 (Eff.) 38 (Eff.) 32 (Eff.)
Dieterle	Mica	$\left\{ \begin{array}{l} 600 \\ 600 \end{array} \right.$	$\begin{array}{c} 50 \\ 50,000 \end{array}$	1.91 1.65

The Effect of Rate of Increase of Voltage. Breakdown voltage varies appreciably with the rate of increase of applied voltage. If, for example, the voltage is increased very rapidly, as to be almost instantaneous, the breakdown voltage obtained is vastly different from that obtained as the result of a slower rate of increase.

There is also a relationship between the applied voltage and the time required for puncture, and this can be shown on a time-voltage curve.

In making comparisons between two or more insulators it is most important that the rate of increase of voltage should be similar.

Specifications take care to stress this point. The B.S. Specification for Varnished Cloth Sheet, No. 419, for example, specifies that the voltage "shall be increased at a uniform rate so that the required voltage is reached in about ten seconds."

There is a little ambiguity in these experimental directions, however, for the specification in question caters for insulating cloth varying in thickness from 5 to 10 mils. It follows, therefore, that the total voltage causing breakdown will be about twice as much for the 10-mil cloth as for the 5-mil cloth, and if care is taken to reach these total voltages in ten seconds, the rate of increase with the former cloth will have to be twice that with the latter. Any differences caused by the variation in rate of increase of voltage are, however, modified somewhat because the above

HIGH-VOLTAGE PUNCTURES IN:

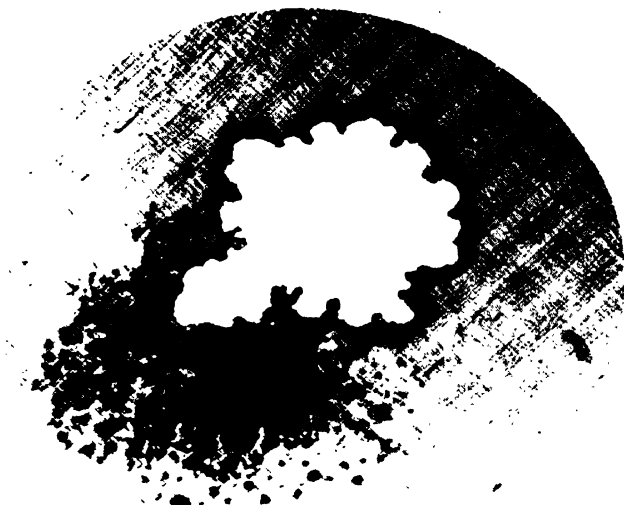


FIG. 32. Varnished cellulose acetate silk. (Magn. 40 dias.)

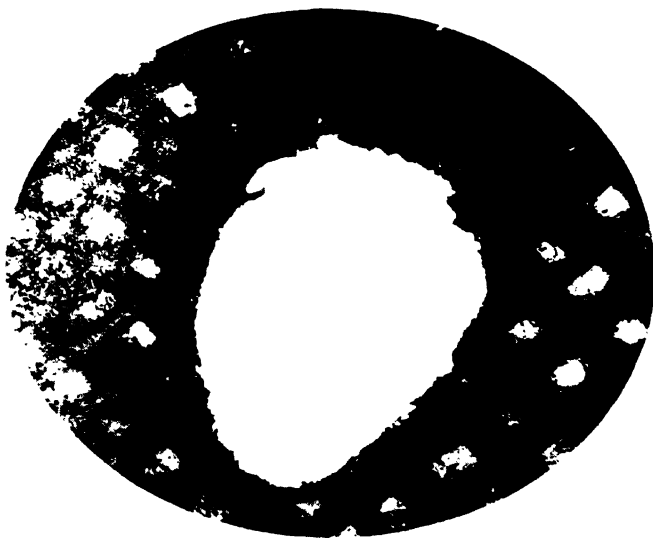


FIG. 33. Varnished calendered cotton. (Magn. 40 dias.)

[To face p. 100.]

specification states that the test voltage shall be applied for one minute. American specifications include a "short time" test wherein the voltage is increased at the rate of 0.5 kV. per sec.

Nuttall (6) prefers to record breakdown voltages not as instantaneous figures, which is a very common procedure, but as the voltage causing breakdown after application for one minute.

Warren (7) also is careful to distinguish between breakdown voltages obtained from rapidly applied voltages and from minute applications.

It is easy to appreciate why some workers report instantaneous figures instead of "minute figures," for the latter entail much tedious repetition work. It is necessary to apply a succession of voltages, increasing by regular increments, until a voltage is reached which just does not cause breakdown after its application for a minute. When six or more such determinations are necessary to arrive at a fair average, the test becomes laborious.

There is another somewhat complicated American test known as the "step by step" test. Starting from a prescribed voltage, the voltage is increased in equal increments up to breakdown—250 volts for cloth up to 8 mils thick, and 500 volts for cloth thicker than 8 mils—each step being of 20 seconds' duration.

A mere bald statement of a single breakdown voltage, or dielectric strength, as so many volts per mil is almost useless. Breakdown voltages vary so much with rate of application of voltage and its ultimate duration, as well as with other factors, that it is essential to provide all the details of the determination when figures are quoted, if they are to be of real value.

For strictly comparative purposes, if the samples under examination are tested under identical conditions, such full details are not, of course, essential.

There is, nevertheless, a purchasing specification in existence for varnished cloth for cables which, in setting down the requirements for dielectric strength, gives no information on the kind of voltage to be employed—D.C. or A.C., its frequency, its rate of increase, or even its duration !

A critical electrical user of varnished cloth will probably test its dielectric strength under the conditions the cloth is likely to meet in use. A cloth might withstand very high instantaneous voltages, but it might easily fail badly at much lower voltages if subjected to them for long periods of time.

This fact has been generally appreciated and tests described as **Maintained Electric Stress (Proof Tests)** have been included in

many Specifications. B.S.S. 419—1931, for example, includes such a test wherein a varnished cloth must withstand a voltage equivalent to 60 volts per mil for two hours without failure.

A tentative standard of the American Society for Testing Materials D295—43T, outlines what is described as an Endurance Dielectric Strength Test. The varnished cloth is first subjected, for thirty minutes, to a voltage equal to 10 per cent. of the breakdown voltage obtained in a short time test. The voltage is then increased in a series of equal steps, each step being 20 per cent. of the initial value and maintained for thirty minutes. The voltage is thus increased until breakdown occurs.

The following figures due to Montsinger (3), illustrate how the breakdown voltage diminishes with duration of application.

Table 21
Variation of Breakdown Voltage with Duration of Applied Electric Stress

	B.D.V. (K.V.) R.M.S.			
	Instantaneous	1 min.	2 mins.	10 mins.
Oil-treated pressboard, tested in oil at 100° C., at frequency of 200 c.p.s. .	105	82	77	71
Ditto, but tested in oil at 25° C. .	80	10 secs. 56	20 secs. 51.5	100 secs. 41.5

The Effect of Size, Shape, and Composition of Electrode. All these factors and, indeed, others, are liable to alter the magnitude of the voltage causing breakdown. There is still some controversy as to the precise effect of some of these influences, and some workers have obtained opposite results from others. In short, therefore, until more research on this subject has completely clarified the position, the manufacturer of varnished cloths and others interested in the intermediates used, should conduct their dielectric strength determinations under standard conditions. If the varnished fabric is to be sold to meet the requirements of a given specification, then the conditions laid down in the specification become standard for testing purposes.

It is, however, a commonly accepted fact that breakdown voltages decrease inversely as the area of the electrodes used. Work done by Farmer (8) for varnished cloth, illustrates clearly

what considerable differences in B.D.V. are obtained with electrodes of different areas. Decreases in B.D.V. per mil up to 40 per cent. are possible if the differences in area of electrode are sufficiently large.

Specifications clearly stipulate the size of the electrode to be used, and require higher breakdown voltages per mil for smaller electrodes. B.S.S. 419—1931 describes its large electrodes as solid brass cylinders, the upper one being $1\frac{1}{2}$ inch diameter and $1\frac{1}{2}$ inch high, and the lower 3 inches diameter and 1 inch high. The smaller electrodes are both $\frac{1}{4}$ inch diameter. For varnished cloth 5 mils thick, the dielectric strength requirements at 90° C. (minute figures) for large and small electrodes, are 450 and 550 volts per mil respectively.

A piece of insulating cloth is likely to vary appreciably in dielectric strength over its area, for there are weak spots arising from various causes, and variations in thickness due to irregular flow of the impregnating varnish. There is a much greater chance of discovering one of these defective points when the surface is explored by a large electrode than when a small electrode is used. To compensate for this the requirements for the large electrodes are less than for the small electrodes.

Using brass electrodes, however, which have very good heat conductivity, the larger area for heat transference means that the temperature of the specimen tends to remain lower than with small electrodes, with a consequent increase in breakdown voltage. Whitehead (9) also points out that increasing the area of electrodes alters the field distribution and diminishes flux concentrations.

Electrodes must be smooth. Mechanically, an electrode with a rough surface or sharp edges may damage a specimen under test, and cause an abnormally low breakdown voltage at this point. Electrically, it has been stated that sharp edges cause low breakdown voltages. It is a fact that the sharper the edge of an electrode the greater the flux concentration, but the effect of these strong fields at the edges of electrodes is uncertain. Although breakdown frequently occurs at the edges of an electrode, the voltage causing breakdown is often of the same order as that causing breakdown in the centre of a specimen.

Uncertainty arising through edge effects is removed by standardising the dimensions of the edge of an electrode. The sharp edges are removed from electrodes, and the radius at the edge is often limited to $\frac{1}{32}$ inch.

The shape of electrodes has an important influence on break-down voltages. Disc, spherical, and needle-point electrodes all behave differently and give different results. Whitehead points out that needle electrodes, in particular, are inclined to give low

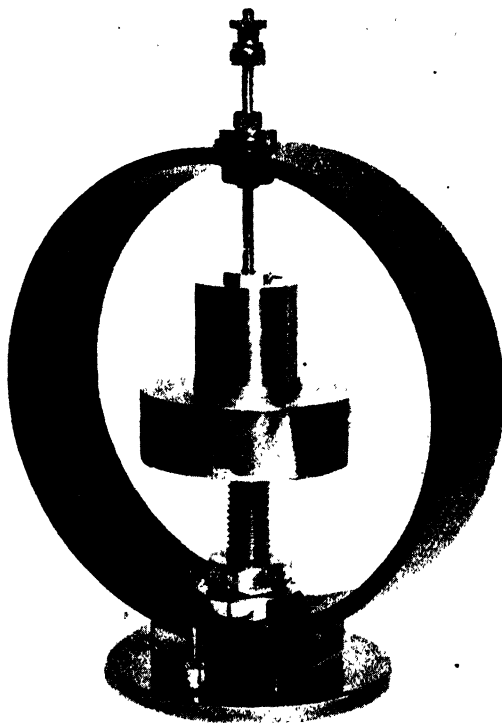


FIG. 34. STANDARD BRASS ELECTRODES.

(By permission of the British Electrical & Allied Industries Research Association, and the Oxford University Press. "Synthetic Resins and Allied Plastics," Morrell).

results, and this suggests that the low results may be caused, in part, by actual damage resulting from the electrostatic attraction between the points (10). As indicated already the usual shape of electrode for testing purposes is a cylinder of specified size. A photograph of standard electrodes is included above.

The actual composition and condition of the electrodes themselves cause differences in breakdown voltage. Again there is no

unanimity in test results obtained by various workers, using electrodes of a variety of compositions, and much seems to depend upon whether instantaneous, minute or maintained breakdown voltages are under consideration. Brass is the common metal for electrodes in most specifications.

Breakdown voltage determinations on materials using electrodes of different composition have been obtained by Raynor (12) with the following interesting results. Two types of electrode were used—brass, and wood covered with tin foil. In every instance the times for breakdown obtained with the wooden electrodes were substantially shorter than those with brass electrodes. The explanation given for these results is that any heat produced is more rapidly conducted through the mass of brass, which is a good conductor of heat, than through wood, which is a poor conductor. Any heat developed, therefore, in the case of wood, is maintained more or less at its place of origin, and this helps to build up quickly a temperature which finally causes combustion or fusion of the insulating material.

Table 22

The Effect of Composition of Electrode on Time Required for Breakdown

Volts Applied	Time of Breakdown (Secs.)	
	Brass Electrodes	Wood Electrodes
9,000	570.0	50.0
10,000	48.0	19.0
11,000	16.5	10.0
12,000	10.2	6.2
14,000	5.2	4.5

The effect of the condition of electrode surface is also doubtful, contradictory results having been recorded. Generally speaking, however, it is convenient and preferable to keep the contact surfaces of electrodes smooth. They should, at all times, be kept scrupulously clean. Frequently, the heat generated during a dielectric strength determination causes considerable softening of the impregnating varnish, and it may adhere to either or both of the electrodes. Removal of this adhering matter is essential between individual determinations.

Tests on thick varnished cloths requiring high voltages for puncture are sometimes upset if the specimens under examination are too small. They should be of sufficient size to prevent flash-over around their edges.

The Effect of Thickness. The dielectric strength of an insulator, as recorded in volts per mil for breakdown, depends upon the actual thickness of the insulator on which the determination is made. The dielectric strength diminishes as the thickness increases, and the curve below shows this clearly.

Varnish films of varying thickness were built up on a Gampi tissue paper base. Comparative dielectric strength determinations show that the value can fall from 1,700 volts per mil for an

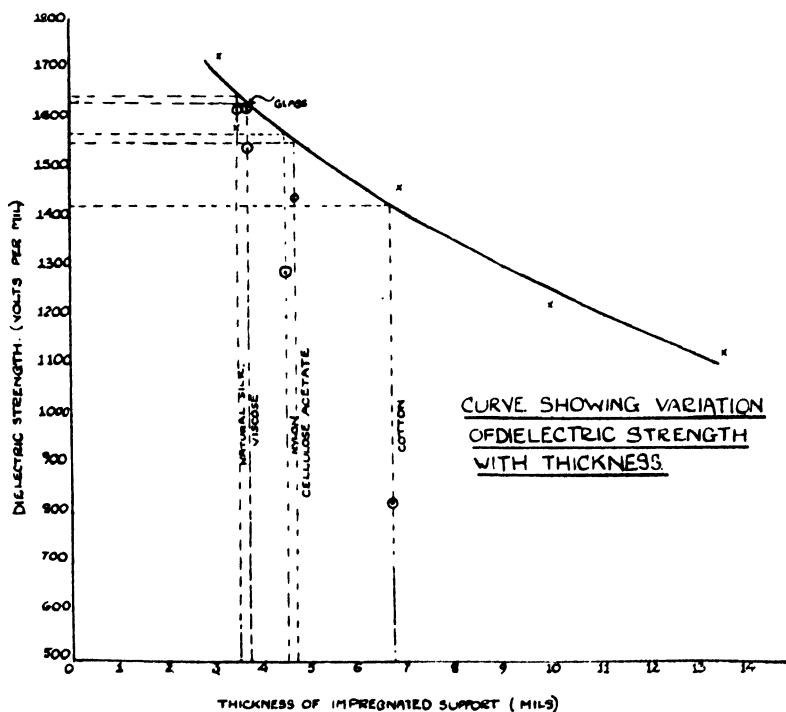


FIG. 35

overall film thickness of 3 mils, to less than 1,100 volts per mil for a film of 14 mils.

In computing the thickness of a varnished cloth to withstand a given voltage this fact must be taken into consideration.

This reduction in dielectric strength with increase in thickness is generally explained on a basis of heat transfer. Heat and electrical conduction in a material usually go hand-in-hand; a poor conductor of heat is a good electrical insulator. Dielectric losses cause substantial generation of heat, and unless this is conducted away rapidly it builds up until ultimately combustion or fusion, and breakdown occur. Varnished cloths are poor conductors of heat, and the thicker they are the smaller the amount of heat which is conducted away. In thick specimens, therefore, the heat is not removed so quickly as in thin specimens, and, in consequence, breakdown occurs at a lower voltage per mil.

It is not impossible to reach a stage when a further increase in thickness produces a reduction in overall breakdown voltage.

The Effect of the Nature of the Support. The nature of the textile or other support has an important bearing on the electrical properties of the varnished cloth or sheet made from it. In quoting dielectric strengths of impregnating varnishes it necessarily follows that the nature of the support used for the determinations should be described simultaneously. It will be seen, however, that the only true indication of the dielectric strength of an impregnating varnish is provided, when the determination is made on a film of it free from all intimate support. Such figures are usually obtained from films of regular thickness applied on smooth brass plates. Even this method is open to the criticism that the brass may inhibit the natural drying process of the varnish, especially if it is necessary for any oxidation to take place during drying. Determinations on films applied to smooth stainless steel panels give better indications of the intrinsic dielectric strength of an impregnating varnish, which are free from the above criticism.

It has been shown already that dielectric strengths, computed as volts per mil, decrease with increase of thickness of the varnished cloth. Calendered cotton, therefore, begins with the disadvantage of exceptional thickness in the raw state, and when impregnated to a uniform cloth, is considerably thicker than other cloths prepared from other supports. Table 23 shows the dielectric strengths of insulating materials, using the same impregnating varnish but different supports.

Table 23**The Dielectric Strengths of Various Textiles Coated with a Synthetic Yellow Insulating Varnish**

Two coats of varnish were applied to each material, and each coat was dried by stoving at 230° F. for 75 minutes. The dielectric strengths were determined at 20° C., with brass electrodes (3 inches and 1½ inch diameter). Voltage increased to breakdown in approximately 10 seconds.

Support	Thickness of Raw Textile Base (mils)	Thickness of Impregnated Textile Base (mil)	Average Dielectric Strength (volts/mil)	
			Varnished Support	Unvarnished Support
Calendered cotton .	5.00 *	6.70	813	125
Nylon . . .	3.15 *	4.53	1287	159
Cellulose acetate . .	2.36 *	4.70	1440	156
Viscose . . .	2.36 *	3.74	1542	141
Natural silk . .	1.57	3.54	1591	215
Glass (continuous fibre)	1.70	3.74	1622	235
Gampi tissue paper .	0.80	3.15	1727	175

* Cotton cloth of 2.0 mils, and rayons of 1.5 mils thick are also in standard use. Experimental work has been successfully performed with nylon fabric 1.5 mils thick.

Calendered cotton base varnished cloth shows up with the lowest dielectric strength, with impregnated Gampi tissue paper as the best. Impregnated Gampi tissue paper is not, unfortunately, satisfactory in other respects, for it has only limited strength. Glass silk, using continuous fibres, although not the thinnest material in the raw state, gives the next highest dielectric strength to Gampi tissue paper.

It may be argued, of course, with some reason, that generally speaking the dielectric strengths recorded in the above table increase with decreasing thickness of the impregnated cloth, but this is by no means the full story. Both impregnated cellulose acetate, and glass silk, although thicker than adjacent impregnated supports, give dielectric strengths which are higher. Furthermore, the curve on p. 106, showing the relationship between dielectric strength and thickness, does not show such wide variations of dielectric strength with thickness, as the variations

of dielectric strength which are revealed in Table 23 with different supports. The impregnating varnish was the same in both series of experiments, and it is at once apparent that there are factors other than overall thickness of various impregnated supports, which influence the resultant dielectric strengths.

If varnished cotton cloth is examined it will be seen that for a 6.7-mil cloth the dielectric strength is about 813 volts per mil. For the same thickness of insulating material based on tissue paper the dielectric strength is 1,420 volts/mil. A drop in dielectric strength of 607 volts/mil has occurred merely because the support has been changed from cotton to tissue paper.

A similar examination of impregnated nylon reveals that for an impregnated fabric of 4.53 mils thick the dielectric strength is 1,287 volts/mil, whereas if tissue paper had been substituted the dielectric strength would be 1,570 volts per mil. In other words, a reduction in dielectric strength of 283 volts per mil occurred because different supports were used.

Table 24 below gives full details of these variations of dielectric strength with different supports, or textile bases.

Table 24
Variation of Dielectric Strength with Type of Support

Textile Base or Support	Average D.S. (volt/mil)	Average Computed D.S. for Impregnated Tissue Paper of Same Overall Thickness	Variation in D.S. because of Substitution of Support	Support Index Figure
Glass (continuous filament) . . .	1622	1630	— 8	2.20
Natural silk . . .	1591	1642	— 51	2.25
Viscose . . .	1542	1630	-- 88	1.58
Cellulose acetate . . .	1440	1550	— 110	1.99
Nylon . . .	1287	1570	— 283	1.44
Calendered cotton .	813	1420	— 607	1.34
Gampi tissue paper .	—	—	—	3.94

Natural silk and glass fabric exhibit no appreciable loss of dielectric strength and appear to be the best supports for insu-

lating cloths, on this basis of assessment. With calendered cotton it is not possible to exploit the valuable electrical insulating properties of the impregnating varnish to the full.

If support index figures are calculated, these seem to be roughly proportional to the dielectric strengths. The support index figure—a term coined by the authors—is used as a measure of the relative amounts of support and varnish. It is calculated by dividing the total thickness of the impregnated support by the thickness of the unimpregnated support. With the exception of impregnated cellulose acetate the support index figures seem to provide some indication of the probable dielectric strength, and it is reasonable to exclude the results with cellulose acetate from any theories which might be developed because it behaves abnormally when impregnated. Before impregnation with varnish, both cellulose acetate and viscose had the same thickness, but after impregnation the cellulose acetate cloth was considerably thicker. Since the varnish used was the same in both cases, it seems that some swelling of the cellulose acetate occurred, caused by the solvent action of the varnish during impregnation.

The dielectric strength of a varnished cloth is of importance to the designer of electrical components, for the higher the dielectric strength the thinner and lighter the cloth which has to be used. This fact is shown quite clearly in the following figures which have been calculated from Table 23, taking Gampi tissue paper as the ideal support, purely from point of view of dielectric strength. The importance of space factor in design has been discussed earlier.

Table 25

Thickness of Varnished Cloths on Various Textile Supports to give the Same Overall Breakdown Voltage

Textile Base or Support	Thickness (mils) to give an Overall Breakdown Voltage of 5,420 Volts
Gampi tissue paper . . .	3.15
Glass (continuous fibre) . . .	3.84
Natural silk	3.41
Viscose	3.51
Cellulose acetate	3.76
Nylon	4.21
Calendered cotton	6.66

The Effect of the Impregnating Varnish or Composition. The impregnating varnish can have a profound effect on the dielectric strength of the resultant insulating cloth. It has been shown already what poor insulating properties the normal textile supports possess, and it is of fundamental importance, therefore, that the varnishes must be carefully formulated, for the value of an insulating cloth depends primarily on their electrical properties.

The table below includes dielectric strengths of yellow varnished cloths processed under identical conditions. It illustrates the effect of composition of the impregnant. Some of them are standard production lines.

Table 26

The Effect of Composition of Impregnating Varnish on Dielectric Strength

Yellow Varnished Cloth (Calendered Cotton Base)		Thickness (mils)	Dielectric Strength (volt/mil), at 20° C. Instantaneous, i.e. 10 secs. to Break- down (Standard 3"—1½" Brass Electrodes)
Series 1	Cloth 1 .	6.1	1,140
	Cloth 2 .	5.4	1,060
	Cloth 3 .	6.0	900
Series 2	Cloth 4 .	8.0	1,380
	Cloth 5 .	8.25	1,250
Series 3	Cloth 6 .	6.25	1,160
	Cloth 7 .	6.3	800

In Chapter IV it has been shown already that an impregnating insulating varnish is a very complicated product. It is only the non-volatile or film-forming portion of the varnish which is of interest from the electrical standpoint, but its composition is little less complicated than that of the original varnish. The non-volatile portion consists of drying oils or their constituent fatty acids, resins, or resin-forming materials of many types, and driers. Other special ingredients are sometimes added also. It is not merely the properties of the different individual constituents which effect the electrical properties of the ultimate dried film, but

the manner and the extent to which these constituents have been processed together during the manufacture of the varnish. Table 27 indicates the dielectric strengths obtained with different drying oils, and also with the same drying oils processed by various means. In considering these results it must be remembered that neither the drying oil nor its constituents represents the whole of the non-volatile portion of the film.

The oils, suitably treated with driers, were all applied on calendered cloth and dried by heating under the same conditions. The dielectric strength was determined at 20° C. by raising the voltage up to breakdown in about 10 seconds, using standard brass electrodes as above.

Table 27
Dielectric Strengths of Drying Oils

Drying Oil				Thickness of Film (mils)	Average Dielectric Strength (volts/mil)
<i>Oil A</i>					
Process A	.	.	.	6.50	392
„ B	.	.	.	7.12	642
„ C	.	.	.	7.05	706
„ D	.	.	.	6.42	527
„ E	.	.	.	6.10	574
„ F	.	.	.	6.18	688
<i>Oil B</i>					
Process C	.	.	.	6.81	720
<i>Oil C</i>					
.	.	.	.	6.18	599
<i>Mixed Oil D</i>					
.	.	.	.	6.73	783

Nuttall (17) has also recorded some interesting figures on the breakdown voltage of linseed oils processed under different conditions, and his results are given in Table 28 shown on p. 118.

It will be seen that these oils increase in viscosity, and it can be reasonably assumed that the viscosity increases are caused by the existence in the oils of larger and more complex molecules. The size of the molecules in linseed oil is readily increased by simple high temperature treatment.

The B.D.V.'s were determined at ordinary room temperature using a standard B.S.I. gap.

Table 28
Electrical Characteristics of Stand Oils

Oil	Viscosity (Redwood)	Acid Value	B.D.V. (20° C.) in K.V.	Power Factor at 70° C.
1. Raw linseed oil	49 secs.	0.8	28	1.2
2. Thin extra pale stand oil	13 mins.	6.0	51	Too low to measure.
3. Enamel oil (extra pale)	14.5 mins.	4.3	74	0.024
4. Medium stand oil	15 mins.	9.5	75	0.185

It follows from these figures that the more complex or more highly polymerised an oil, the higher its breakdown voltage, and this has been attributed to the fact that the increase in viscosity of the oils impedes the movement of ions.

The power factors are interesting, for there is no regular variation in this property. As the degree of polymerisation increases, the power factor falls and then rises again. The high power factor for raw linseed oil is explained by the presence of dipoles, as represented by the many unsaturated linkages, present in it. As the degree of polymerisation increases, the unsaturated linkages become partly satisfied and the power factor drops. It is suggested that the subsequent increase in power factor on further polymerisation is because of an increase in free acidity in the oil.

Using Drying Oil A, process C, various resins natural and synthetic, were incorporated in similar amounts, and the dielectric strengths of the mixtures are shown in Table 29.

Table 29
The Effect of Natural and Synthetic Resins on the Dielectric Strength of Drying Oils

Drying Oil/Resin Mixture	Thickness of Film (mils)	Average Dielectric Strength (volts/mil)
Oil A, process C alone	7.05	706
+ Resin 1	6.10	653
+ „ 2	6.61	658
+ „ 3	6.81	700
+ „ 4	6.65	701
+ „ 5	6.74	809
+ „ 6	6.30	822

These results prove that the resin can influence the dielectric strength of an oil, in that it may be increased or decreased. Some resins apparently do not cause any substantial change.

The results given in Tables 27 and 29 are for experiments conducted on a few only of the available drying oils, and their mixtures, and on a few resin combinations. Those who are associated in any way with the varnish trade, or who are cognisant of the multitude of varnish constituents available, well know that these experiments represent merely an exploration into the fringe of the possibilities—the number of drying oil and synthetic resin combinations is legion. Work is progressing continuously to exploit their properties to the full, and new and better impregnating insulating varnishes will be born in the immediate future, as successful conclusions to these researches are reached.

The Effect of Drying Conditions of the Impregnating Varnish. It has been discussed already how the dielectric strength of a varnished cloth can be influenced by the nature of the support on which the varnish applied, and by the composition of the varnish itself. The actual drying conditions, whereby the liquid varnish is converted to a solid flexible film, also exert a profound influence on the dielectric strength of the resultant cloth. Table 30 shows the dielectric strengths obtained on calendered cotton cloth by subjecting the varnish to different drying temperatures for different times.

To obtain the highest dielectric strength, therefore, the varnish must be thoroughly dried, and thorough drying is assured either by increasing the drying time or the raising of the stoving temperature. As the drying time at 230° F. is increased from half an hour to two hours, the dielectric strength increases simultaneously from 1,162 volts/mil to 1,553 volts/mil. From the proofer's point of view it is much more lucrative to rush the impregnated cloth through the drying tower, because this means increased output in a given time, but the output is obtained at the expense of quality. Every varnish has optimum drying conditions, and a few experimental runs through the tower soon discover them. The varnish formulator, of course, seeks to accommodate the stipulated drying conditions of the proofer's tower by providing a varnish which yields the best results under these conditions. Having done this, it is disastrous if the proofer succumbs to the temptation to shorten the drying time by increasing the running speed.

Table 30

Variation of Dielectric Strength with the Drying Conditions of the Impregnating Varnish

The following dielectric strengths were obtained from the same varnish on glass silk. Two coats of varnish were applied and dried at different temperatures.

The dielectric strengths recorded are instantaneous figures at 20° C. and 50 cycles per second, the breakdown voltage being reached in about 10 seconds. Brass electrodes 3 inches and 1½ inches were used.

Stoving Conditions	Thickness of Coated Silk (mils)	Dielectric Strength (volts/mi)
230° F/½ hour each coat . .	3.90	1,162
230° F/1½ hours each coat .	3.74	1,412
230° F/1½ hours first coat . . 280° F/2 hours second coat .	} 3.54	1,553
180° F/2 hours each coat . .	4.30	1,247
270° F/¾ hour each coat . .	3.74	1,305

Broadly speaking, the same results in dielectric strength can be obtained by making adjustments either in temperature or stoving time, that is, if the temperature is reduced the duration of treatment will have to be prolonged or *vice versa*. A longer time of treatment compensates substantially for a lower temperature: at 180° F., for example, if the stoving time is increased to two hours, a dielectric strength of 1,247 volts/mil is obtained which is actually in excess of the figure of 1,162 volts per mil obtained from half an hour's treatment at 230° F. This result is, however, less than the 1,412 volts per mil, for 1½ hours' treatment at 230° F., but it is reasonable to suppose that if the treatment at 180° F. is extended sufficiently beyond two hours, it too would yield a dielectric strength of 1,412 volts per mil. The time required in practice, however, to produce this result would be considered uneconomical.

Again, for proofers it is easier and cheaper to attain and maintain low temperatures; 180° F., for example, can be obtained by very low pressure steam, but 270° F. requires a steam supply at a much higher pressure. But at 270° F. for forty-five minutes a higher dielectric strength is obtained than after treatment for two hours at 180° F.

The results in the above table are not absolutely applicable, without modification, to every impregnating varnish, but they indicate the general effect of temperature and duration of treatment.

The foregoing is not quite complete on this aspect of the subject, for the type of drying which occurs at low temperatures is quite different from that which occurs at high temperatures. In the former, oxidation of an oxidisable film is more probable than polymerisation, and therefore low temperature varnished cloths tend to be more oxidised than high temperature cloths, which, by contrast, are more highly polymerised. It is reasonable to suppose that the electrical properties of oxidised films differ, in some degree, from those of polymerised films. Apart from any difference in electrical properties, high temperature cloths are usually preferable to those prepared at low temperatures. The reasons for this assertion are discussed in detail later in this chapter.

Nuttall (17) has conducted some interesting experiments on varnish films, the drying process of which was allowed to proceed at ordinary atmospheric temperatures. In other words, the varnish had every opportunity to oxidise.

A piece of cloth was treated with a straight medium linseed stand oil containing a convenient amount of lead and manganese driers. The oil on the cloth was partly dried and left in a soft and tacky condition. The breakdown voltage was then determined at intervals until no further hardening or drying of the oil occurred. The degree of drying, or hardness of the film, was measured by determining the elongation of the films under a standard tension, on the assumption that hardness is inversely proportional to elongation.

One-inch bias-cut tapes, carefully conditioned at 75 per cent. humidity were used, and the elongations were produced by a tension of 2 lbs. applied for five minutes.

The curves shown on p. 117, indicate that the breakdown voltage of varnished cloth, even when dried at low temperatures where considerable oxidation takes place, increases as the varnish dries or hardens. From this it follows that for best results from

an impregnating varnish, irrespective of the drying temperature, it should be thoroughly dried.

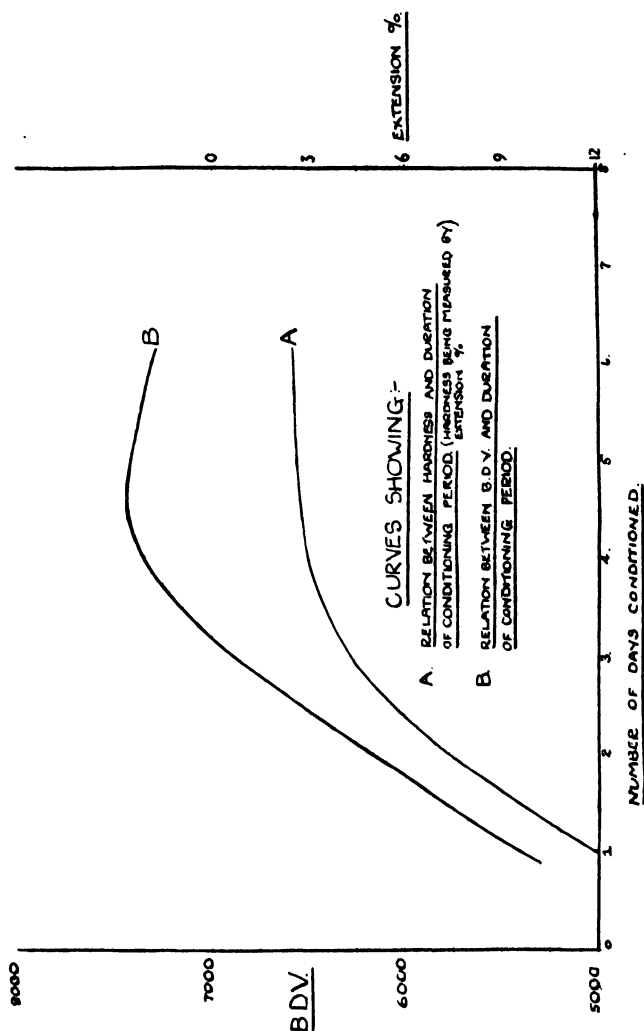


FIG. 36

It is not improbable that impregnating varnishes will be devised, or may be in existence already, which do not dry by oxidation at any temperature, but by a thermo-hardening process. Nevertheless, it is essential for them to be dried above a certain minimum

temperature, for thermo-hardening processes are often very critical of temperature, and below a definite minimum no marked change in the physical condition of the film takes place. There are not likely to be marked differences in the properties of films of such materials stoved at different temperatures, provided the temperatures are above the critical minimum, and the film is stoved until it has completely thermoset.

Reverting again to the work of Nuttall on the relation between hardness and breakdown voltage, the curves A and B show a remarkable similarity for the first three or four days. This similarity disappeared subsequently and the breakdown voltage increased at a much greater rate than anticipated. The initial similarity, however, seemed to form the foundation of a theory that hardness and breakdown voltage were directly connected, and further experiments were conducted. Three alkyd resins of varying composition and increasing hardness were made, namely, a phthalic anhydride—glycerol resin modified with 22 per cent. adipic acid; a similar resin using 18.5 per cent. of succinic acid as the modifying agent in place of the adipic acid; and a straight unmodified phthalic anhydride-glycerol resin. These are placed in order of increasing hardness, but the dielectric strengths determined at 20° C. were in the opposite order from that required by the theory, for the hardest resin (the straight alkyd) had a dielectric strength of only 264 volts/mil, whereas the adipic acid resin which was the softest had a dielectric strength of 535 volts/mil. The succinic acid resin which was intermediate in hardness gave a figure of 471 volts/mil.

These results show that there is no real connection between the property of hardness generally and dielectric strength. For products of identical composition which have been converted into a higher state of molecular complexity by heat treatment, either before or after application to the textile support, the dielectric strength increases with molecular size. Increase in the molecule, on the other hand, is accompanied by increases in viscosity and hardness. The increase in hardness is recognised by a reduction in flexibility of the varnished cloth. There is, however, no evidence to connect flexibility of varnished cloths in general with dielectric strength, for the connection exists only with cloths prepared from impregnating insulating varnishes of the same composition. For proofers and others who may be stoving a given varnish under varying conditions, a comparison of flexibilities of the resultant cloths may be a rough guide to their

dielectric strengths. For varnishes, however, of differing composition, it is quite possible that very flexible varnished cloths will be obtained with dielectric strengths considerably in excess of those prepared from more rigid varnishes.

The Effect of Temperature on Dielectric Strength. Temperature has a very important influence on the dielectric strengths of varnished cloths, and its influence is governed by its magnitude.

Increases of temperatures always result in a reduction of dielectric strength, if the duration of the heating is insufficient to cause further substantial oxidation or polymerisation of the varnish. If the cloth is subjected to hot conditions for a considerable period, these changes are quite likely to occur, and an increase in dielectric strength may result, to modify or even reverse the normal reduction consequent upon a rise of temperature.

Because of the possibility of subjection to a high temperature producing profound changes in the dielectric strength of a dried varnish film, many specifications, which insist on dielectric strength determinations at 90° C. (194° F.) or higher, lay themselves open to criticism. British Standard Specification 419—1931, describes a dielectric strength test on varnished cloth, wherein the specimen is *heated at 90° C. for not less than one hour and not more than two hours before it is placed between the electrodes*. The figures quoted in Table 31 for a standard yellow impregnating varnish, indicate that initially inferior cloths, when subjected to stoving conditions of 90° C. (194° F.) for a further period of two hours, would yield greatly enhanced dielectric strengths. If the specification test is designed to detect any likely reduction in dielectric strength with increase of temperature, it is certain to fail in many instances such as these.

It is, of course, appreciated that certain types of electrical equipment function at temperatures substantially in excess of prevailing air temperatures, and for this reason the dielectric strength of a varnished cloth must be adequate under these conditions. Since some inferior varnished cloths, however, show an improvement in this property at a higher maintained temperature, the test is of doubtful value. On the other hand, the test cannot have been designed as a means of detecting resistance to general disintegration of the varnish film at elevated temperature, for at 90° C. the duration of heating is too short to be effective.

The extent to which the dielectric strengths of varnished cloths, as supplied to the electrical trade, are modified by the

heating at 90° C. as required in specified tests, will depend partly upon the age of the sample under consideration, and the conditions applying during its storage. If initially the varnish on the cloth were rushed through a tower so that on emerging it was incompletely dry, but subsequently it was held in storage for several months before despatch, there would be a good chance that the drying process would have progressed markedly towards completion during this period of storage. If there were an adequate supply of air and the cloth was in the form of loosely-packed sheets or rolls, the conditions would be very favourable for continued oxidation. It follows, therefore, that the drying conditions outlined in the specification are most favourable to fresh samples of incompletely dried varnished cloth. Older samples will not be effected by this treatment to such a marked degree. The dielectric strengths of old and initially well-dried varnished cloths might be only slightly improved by the heating at 90° C., and in some cases the normal reduction in dielectric strength consequent upon an increase in temperature might swamp this slight improvement—a net reduction in dielectric strength would result. It is much more difficult to dry black varnished cloths thoroughly, because the black constituents of black varnishes frequently act as powerful inhibitors. It is not surprising, therefore, that many black varnished cloths tend to complete an unfinished drying process during the specified two hours' heat treatment of the dielectric strength test.

As the test is at present outlined, it is a little difficult to understand what useful property it measures.

It is granted that a means of determining dielectric strength at elevated temperatures is necessary, and the authors have felt for a long time that this could be achieved satisfactorily without introducing other complications, by maintaining the specimen of varnished cloth under test at 90° C., only long enough for it to attain this temperature. A few minutes in a heated cabinet to allow any moisture in the film to disappear without obstruction, followed by a few minutes between the heated electrodes, should suffice. This is borne out by the following experimental figures.

Several samples of yellow and black varnished cloth were taken at random from stock, and their dielectric strengths were determined under three different sets of conditions.

1. Ordinary atmospheric conditions.
2. After heating at 90° C. for two hours.
3. After heating at 90° C. for five minutes, free of electrodes to

permit removal of absorbed moisture, followed by five minutes between the electrodes to permit the test specimen to reach 90° C.

All dielectric strengths are instantaneous figures (*i.e.*, ten seconds up to breakdown), at 50 cycles, with standard brass electrodes.

Table 31

The Effect of Temperature on the Dielectric Strength of Varnished Cloths

Varnished Cloth	Dielectric Strengths under Different Conditions (volts/mil)		
	1	2	3
Yellow cloth A . . .	748	714	451
Yellow cloth B . . .	1,338	1,014	627
Yellow cloth C . . .	866	735	518
Black cloth A . . .	792	934	714
Black cloth B . . .	603	778	550

The designer of electrical equipment is interested to know the dielectric strength of varnished cloth under the following conditions to ascertain the influence of temperature.

1. Under ordinary climatic conditions of temperature and humidity, for each piece of electrical equipment is used under these conditions at certain times in its life.

2. When it first reaches its average maximum operating temperature. The time taken for this may be a few minutes or an hour or so, but if the dielectric strength at the operating temperature is determined *immediately* the test specimen attains this temperature, which will be a few minutes only, it will provide the information required.

3. After the varnished cloth has been at the average maximum operating temperature for many hours. This is a measure of film degradation, and is disregarded for the moment because it involves other factors.

Flight (11) has conducted research on the reduction of dielectric strength with increase of temperature, and the curve reproduced on p. 122 for varnished cloth is conclusive.

The influence of temperature on dielectric strength cannot be ignored. At the usual operating temperatures of electrical machines the variation is of considerable magnitude. Over the temperature range from 25° to 75° C., the breakdown voltage halves itself for three layers of cloth, and for one layer there is roughly a 40 per cent. decrease.

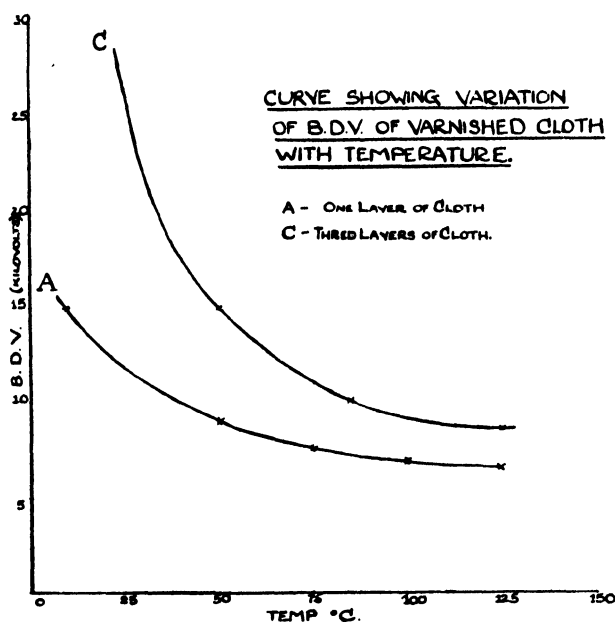


FIG. 37

The same worker conducted another series of tests on various insulating materials at different temperatures by immersing them in transformer oil. He was careful to avoid any complications due to the possible presence of moisture in the materials, by drying them at 80° to 90° C. for two to three days. This treatment, incidentally, had the effect also of thoroughly oxidising and/or polymerising any impregnating varnish, so that the subsequent short heating at 100° C. during the breakdown voltage determination caused little if any change in the varnishes, which might bring about an increase in breakdown voltage.

Table 32
Variation of Breakdown Voltage with Temperature

Material	B.D.V. in Transformer Oil (K.V.)		Percentage Decrease in B.D.V.
	At 30° C.	At 100° C.	
Paper	32.2	23.5	16.5
Varnished cloth	30.7	22.1	24.6
Varnished paper	38.5	17.7	54.0

The Effect of Abnormally High Temperatures. It has been discussed already that in raising the temperature of a varnished cloth from air temperature to 90° C., which has been chosen as an average operating temperature, two changes may occur in the dielectric strength. Firstly, a continuation of the drying processes of the varnish may be encouraged, resulting in an increase of dielectric strength, and secondly, a natural reduction in dielectric strength may result with increase of temperature—a common phenomenon with insulating materials generally.

In recent years a demand has arisen for varnished cloths which will withstand abnormally high temperatures. Temperatures of the order of 150°–200° C., or higher, are cited. Many advantages accrue from electrical machines if they can be designed to operate continuously at these elevated temperatures. This demand for high-temperature insulators has revealed many new facts—some disturbing, others interesting.

Two difficulties were soon encountered. Until glass-woven fabrics became available none of the existing textile supports were capable of resisting temperatures of 150°–200° C. indefinitely, without betraying unmistakable signs of disintegration. The introduction of glass continuous filament fabrics solved one difficulty, but it was soon discovered that none of the usual impregnating varnishes was entirely satisfactory for high-temperature conditions. This problem is even yet by no means solved, and the advent of improved heat-resisting varnishes may be anticipated from time to time in the efforts to reach perfection.

A temperature of 150° C. (302° F.) is an unusually high one for organic insulating varnishes, and although some varnishes may be hardly affected, if initially well dried, after a further exposure to 90° C., it is almost certain that the same varnishes will be altered considerably at 150° C.

Subjection to a temperature of 150° C. or higher causes much darkening, which gets progressively more intense as the heating is prolonged, or as the temperature is raised still higher. The colour goes through many stages of reddish brown until finally it becomes black. The process is really one of gradual carbonisation. Simultaneously with this colour change the cloth becomes less and less flexible. In the end, on cooling again, the cloth is too brittle to withstand even a slight bend without fracturing.

It is a natural assumption to make that since the varnish film is apparently gradually being destroyed, its dielectric strength will diminish proportionately. Precisely the opposite is true, however, for prolonged heating at these elevated temperatures nearly always produces a noticeable improvement in dielectric strength. Of course, ultimately, when the varnish film begins to crack or disappear, dielectric strength falls away.

The following figures are typical of the increases in dielectric strength obtained with various varnishes on glass silk, after heating the varnished silk at 150° C. for 100 hours.

Table 33

The Effect of Abnormal Temperatures (150°–205° C.) on the Dielectric Strength of Varnished Glass Silk

Varnished Glass Silk	Dielectric Strength (volts/mil) (initial)	Dielectric Strength after Heating at 150° C. for 100 Hours (volts/mil)	Dielectric Strength after Heating at 205° C. for 24 Hours (volts/mil)
A	1,167	1,674	—
B	1,593	1,717	—
C	1,001	1,513	—
D	882	1,410	—
E	1,211	—	1,619
F	1,273	1,740	—
G	1,225	1,740	—
H	1,645	1,910	—

These figures demonstrate that with good quality insulating varnishes of widely varying composition, considerable improvements in dielectric strength are obtained on prolonged heating at high temperatures. Contrary to expectation the dielectric strength does not noticeably diminish with increased carbonisation of the varnish film, and it seems that the heating brings about other complex changes in the varnish film which yield a substantial overall increase. Considerable disintegration of the film has to take place before electrical failure occurs, and even so, failure is often caused by the excessive brittleness developed leading to fractures.

The Effect of Moisture. Moisture has probably the greatest

effect of any external influence in reducing the dielectric strength of varnished cloths. This is a fact which has long been recognised, and most specifications are careful to stipulate the precise conditions of humidity at which dielectric strength determinations are to be made.

When careful examinations are instituted, it is surprising how many apparently inert materials absorb or adsorb at least minute traces of water, and it is equally surprising the disastrous results which absorbed water has on dielectric strength and insulation resistance.

The effect of water on the breakdown voltage of hydrocarbon oil has been studied by Peck (13). Using as electrodes $\frac{1}{4}$ inch discs, $\frac{1}{2}$ inch apart, he showed that 1 part of water per 10,000 parts of oil produced a reduction in breakdown voltage from 60 to 19 kilovolts; 7 parts of water per 10,000 parts of oil caused a further reduction to 10 kilovolts. This is remarkable when it is commonly held that for all normal purposes hydrocarbon oils and water have no affinity for each other.

Varnished cloths are made up in the main of two components—the textile support and the dried varnish film. Of these two components the textile support is the most unreliable with respect to water absorption. In a state of equilibrium all textile supports contain or hold appreciable amounts of water. This is true even for glass fabrics, which by surface adsorption hold traces of moisture on the unprotected filaments.

Work by Evershed (14) has shown that when fibrous insulations such as cotton, natural and artificial silk, etc., are subjected to an increasing voltage, the insulation resistance diminishes. The implication is that they do not obey Ohm's law. Evershed attributes this fall in insulation resistance to the presence of moisture.

The accompanying curves on p. 126, drawn for convenience together, based on Evershed's work, show the reduction in insulation resistance of cotton, before and after baking. Curve A represents the reduction in insulation resistance of cotton containing its natural amount of moisture; Curve B shows a smaller reduction in resistance after much of the moisture had been removed by prolonged baking. At 200 volts undried natural cotton had an insulation resistance of about 2.25 megohms; after drying it had improved to 200 megohms. In spite of the baking it is quite certain that a very appreciable reduction in resistance is caused by moisture which is tenaciously held.

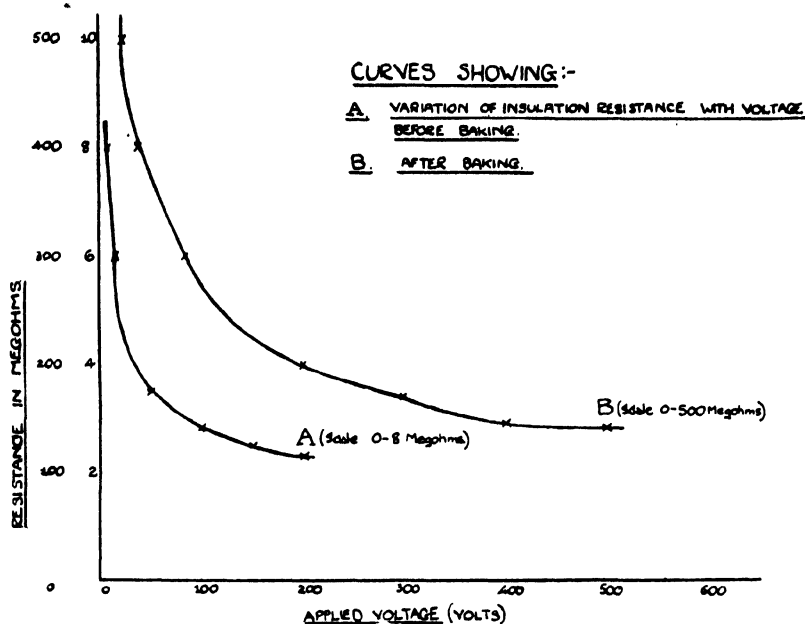


FIG. 88

During the manufacture of varnished cloths, it is not usual to dry the raw cloths by heating, before impregnating with varnish; but this does not mean necessarily that the varnish is applied over moist cloth and that all the moisture is sealed in. During the drying process of the varnish, which involves heating, some, but not necessarily all, of the moisture is sure to be evaporated off with the thinners of the varnish. Even after the varnish film has set, it is not inconceivable that more water vapour would diffuse through it at the high temperatures used. Under ideal proofing conditions it should be arranged so that the moisture content of the textile support is reduced to zero, or as near to zero as is practical, and whilst maintaining these conditions the insulating varnish should be applied. This treatment would involve the use of somewhat complicated drying arrangements for the raw cloth, and special varnish dipping troughs, and as far as the authors are aware, no such plants are in operation.

Thus the textile supports are not free from the defect of hygroscopicity, and the same is true of insulating varnishes, but to a lesser degree. The dielectric strengths of varnished cloths depend

a good deal on the moisture resistance of the film of insulating varnish. It has been shown already how the presence of traces of water in an hydrocarbon oil can decimate its breakdown voltage, and likewise with a varnished cloth. The moisture resistance of an insulating varnish depends upon three factors, namely, the composition of the varnish itself, its treatment during manufacture, and on the stoving or drying conditions after it has been applied to the raw cloth.

In an interesting paper by Wilkinson and Figg (15), curves are given for the moisture absorption of varnish films after immersion in water. Several important points are made.

Astonishing percentages of water were absorbed, amounting to as much as 100 per cent. after fourteen days' immersion, and 19 per cent. after two days' immersion. The amount of water absorbed was inversely proportional to the thickness of film, and for the thickest film the percentage absorption was 37 per cent. approximately in the fourteen-day period, or 6 per cent. after two days' immersion.

These absorptions look very bad against present-day standards, for with the introduction of synthetic resins air-drying varnishes with water absorptions of less than 1 per cent. after two days' immersion are produced.

Insulating varnishes for cloth are, however, dried by heating, and high temperature drying has the effect of greatly increasing the moisture resistance of varnish films. The moisture absorptions, therefore, of insulating cloths are likely to be of the order of fractional percentages only. In spite of this the small amount of moisture which is absorbed causes marked reductions in insulation resistance and in dielectric strength. Table 34 shows two things, firstly the striking reductions in dielectric strength which occur after exposing dry varnished cloth to moist atmospheres, and secondly how the extent of the reduction can be modified by varying the composition of the varnish.

The insulators in Group I are drying oils which have been subjected to different forms of treatment. The dielectric strengths are instantaneous figures, *i.e.*, ten seconds up to breakdown at 50 cycles, with standard 3-inch and 1½-inch brass electrodes, and were obtained on impregnated calendered cloth. Initial dielectric strengths were obtained on varnished cloths, aged seven days under normal atmospheric conditions, and stoved half an hour at 90° C., just prior to testing, in order to ensure that a minimum amount of moisture was left in the cloth. The di-

Table 34

The Effect of Moisture on the Dielectric Strength of Varnished Cloth

Insulator (Varnish Ingredients and Varnishes)	Film Thickness (mils)	Initial Dielectric Strength (volts/mil)	Dielectric Strength after Exposure to Humid Atmosphere (volts/mil)	Percentage Decrease in Dielectric Strength (volts/mil)
GROUP I :				
<i>Drying Oil A :</i>				
Process A .	6.50	392	263	32.1
Process C .	7.05	706	295	58.2
Process D .	6.42	527	251	52.3
<i>Mixed Oil D</i> .	6.73	783	384	51.0
<i>Mixed Oil E</i> .	6.34	716	383	46.5
<i>Drying Oil D</i> .	6.18	599	348	41.9
<i>Special Treated Oil</i> .	5.99	690	638	7.5
GROUP II :				
<i>Yellow Insulating Varnishes :</i>				
A	—	1,167	620	46.8
B	—	1,593	1,013	36.4
C	—	1,002	770	23.1
D	—	1,204	890	26.1
E	—	1,211	578 (549)	52.2 (54.6)
I	—	882	359 (302)	59.0 (65.7)

electric strengths after exposure to humid conditions were obtained on the same specimens of varnished cloth as previously, which had been aged seven days under normal atmospheric conditions, but which were then subjected to a saturated atmosphere (100 per cent. humidity) at 60° F. for eighteen hours. The results of Group I show clearly that drying oils (or their components), although they do not make up the entire insulating varnish, are likely to cause profound differences in electrical properties under humid conditions. Different oils behave differently under these conditions, and the processing treatment is also liable to cause substantial variations in dielectric strength. Using a specially treated oil it is possible to reduce the percentage reduction of dielectric strength under humid conditions to as little as 7.5 per cent.

The insulators in Group II are all typical yellow insulating varnishes applied on glass fabric. They are entirely synthetic in character and contain no uncombined vegetable drying oils. The initial dielectric strength figures were obtained under the same

conditions as the figures of Group I, except the specimens were tested immediately after they received the heat treatment necessary for drying. The dielectric strengths were determined also after subjection to 100 per cent. humidity for eighteen hours. The figures in brackets were obtained on specimens immersed in water for eighteen hours, dried carefully with blotting paper, and tested in an atmosphere of 100 per cent. humidity. A comparison between the dielectric strengths obtained after exposure to water vapour and liquid water, indicates that although the latter exposure conditions are the more severe, the differences are not so great as might be expected.

In assessing the quality of retention of dielectric strength of insulating varnished cloths under moist conditions, it is not merely the percentage reduction in dielectric strength calculated on a basis of initial dielectric strength which has to be considered. The real criterion of a good varnished cloth for humid conditions is the actual magnitude of the dielectric strength under these conditions. A synthetic yellow insulating varnish with an initial dielectric strength of 1,598 volt/mil, which drops by 86.4 per cent. to 1,018 volts/mil under humid conditions, is obviously of more value as an insulator than a varnish which initially has a dielectric strength of 1,204 volts/mil, and only loses 26.1 per cent. of this value on exposure.

The Mechanical Strength of Varnished Cloths

The mechanical strength of varnished cloth is a very important property, for often in the construction of electrical components appreciable force is applied to the cloth. It must accommodate this force without simultaneous disintegration. When varnished cloth, in the form of tape, is used for binding coils or for lapping cables, a tensile force is applied in the process, and it is necessary to retain at least a proportion of this force to keep the tape in place. When lapped cables have to be bent for any purpose, for example, when they are fed on to or removed from their large wooden formers, or coaxed into awkward positions when laid, the tape on the outer circumference of the curves is subjected to an increased tension.

Varnished cloth should be strong enough, therefore, to withstand any reasonable force to which it might be subjected in use. The difficulty is to estimate the strength of the cloth in advance in order to eliminate chance of failure.

The forces which are applied to cloth are neither purely tensile

nor essentially shear, but probably a complex combination of both; and to make the matter even more complicated it must be remembered that cloth consists of woven threads—warp and weft—at right angles to each other. These individual threads are twisted so that their component filaments do not lie exactly parallel to the direction of the length of the thread, but assume a spiral form, which in turn varies according to the amount of twist which the thread is given during manufacture. Furthermore, the construction of warp and weft threads need not necessarily be identical, and in practice their respective mechanical strengths after impregnation with varnish, vary considerably. Thus to obtain a truer assessment of the strengths of varnished cloths, it is usual to conduct three different types of strength tests upon them, namely, tensile, tearing and bursting strength tests. All of these tests may be conducted advantageously, either by the raw textile manufacturer, or by the proofer before he applies the varnish, for if the untreated cloth is weak before impregnation it is almost certain to be equally weak afterwards. The application of impregnating varnish to raw cloth cannot be relied upon to improve its strength. Proofers, therefore, who supply varnished cloth to meet specifications with definite mechanical strength requirements, satisfy themselves that the raw cloth itself is strong enough to meet these requirements with some margin to spare. In the chapter devoted to the textile supports, it has been explained how weak and defective cloths arise.

Tensile strength figures are a measure of the strength of raw or varnished cloth under the influence of a direct pull, either parallel with or at right angles to the warp threads. The unit of measurement is the number of pounds causing fracture per inch width of material. Sometimes the figures are expressed as pounds per 8, 4 or 6 inch widths of material. Tensile strength determinations are measured in both directions, because although an ideal cloth should be equally strong in the warp and in the weft threads, this is by no means always the case. B.S.S. 419—1981, for varnished cloth, permits the minimum tensile strength in the weft direction to be substantially less than that in the warp direction. The minimum allowable tensile strength reductions in the weft direction, by comparison with corresponding warp strengths, vary according to the nominal thickness of the cloth. For a five-mil cloth the minimum weft tensile strength is 60 per cent. of the warp strength; for a seven-mil cloth it is 66·6 per cent.; and for a ten-mil cloth it is 71·4 per cent.

That there are differences in warp and weft strengths is not surprising, for even assuming both threads to be of identical construction, the warp thread is always sized to facilitate manufacture of the cloth, and the amount of twist differs. Careful scouring will not remove all traces of size, and any residual size will impede free movement of the fibres or filaments of the threads. There are other theories also which are advanced to account for the differences in strength of the two types of thread.

The bursting strength test attempts to take into account simultaneously the strength of both warp and weft threads, and is conducted by applying a gradually increasing air pressure to a diaphragm of the varnished cloth held between clamps. The results are reported as the pounds per square inch of varnished cloth required to cause failure. Minimum bursting strength requirements increase with thickness.

One of the greatest dangers in using varnished tape, when it is being lapped round cables or used on other components, is that of tearing from the edges, and this is the reason for the inclusion of tearing strength figures in specifications. Again, two types of tear are considered; a warp tear, wherein the direction of the tear is across the weft threads, and a weft tear, wherein the direction of the tear is across the warp threads. As with tensile strength figures, the requirement for the warp tearing strength, which is, in effect, a measure of the strength of weft threads is lower than that for the weft tearing strength. The actual test consists in measuring the force necessary to tear a tongue out of the cloth at a uniform rate. A double tear is made and the force is recorded as the number of pounds required to tear out a tongue 2 inches wide.

When the strength of cotton fabrics is impaired, the viscosity of the solution which it yields in cuprammonium reagent is altered. These viscosity determinations are used as a means of assessing mechanical strength, not only of raw unimpregnated cottons, but of varnished cottons as well. The details of the method are given in Chapter IX, and by means of viscosity determinations it is possible to obtain an idea of the degradation of both raw and varnished cotton, resulting from storage, and on varnished cotton as the immediate result of applying and drying an impregnating varnish on it. In order to prepare solutions of cotton in cuprammonium reagent from varnished cotton, it is first necessary to remove the dried varnish, but this is easily

accomplished by boiling with dilute aqueous or alcoholic caustic potash or caustic soda.

Varnished cloth is supplied in two forms :—straight and bias cut. Bias cut tape is much more difficult to tear than straight cut tape when the tearing force is applied exactly normal to the edge of the tape. When bias cut tape is tested for tensile strength by a pull at right angles to the width of the tape, much elongation occurs before failure, whereas with straight cut tape the elongation under similar conditions is insignificant.

The strength of textiles, whether tensile, tearing or bursting, varies according to the prevailing atmospheric conditions. The moisture absorption of the textile, whether raw or impregnated, is governed by the relative humidity of the atmosphere which surrounds it, and it is therefore of fundamental importance for test purposes, that all test pieces of varnished cloth are carefully stored under specified temperature and humidity conditions before testing. Ideally, tests for strength should be conducted under standard conditions, but because of the difficulties involved in accomplishing this, it is stipulated that the test is conducted within two or three minutes of removal from the controlled conditions, and this procedure has proved satisfactory in practice. Monaghan (19) states that for cotton the tensile strength from the bone dry state to a moisture content of 8 per cent., increases approximately 7 per cent. for each 1 per cent. of added moisture.

Impregnating varnishes vary considerably in their effects on the strength of fabrics. On cotton, for example, improvements in tensile strength after impregnation are often observed. More frequently, however, substantial reductions in strength occur. The extent to which the strength of fabrics is altered by a probable chemical attack depends not only on the composition of the impregnating varnish but on the composition of the textile support. Glass fabrics are inert to all the normal ingredients of impregnating varnishes, and hence their strengths are but little influenced as the result of chemical attack, when in contact with them. Natural silk also retains its strength to a satisfactory degree after impregnation. Viscose, cuprammonium and cellulose acetate silks are very much affected by varnishes, but the effect on strength can be considerably reduced, and in some instances completely eradicated. By the judicious selection of varnish ingredients it is possible to improve the resulting strength of rayons after impregnation, although, of course, the restriction of movement of individual

filaments must cause a diminution in strength by comparison with that of the untreated textile.

Cellulose acetate is peculiar in its tendency to be attacked, for unlike all the other materials of textiles, its filaments are soluble in certain varnish solvents. This is not such a serious matter as it might appear, for such solvents, except perhaps in a few cases with some types of synthetic resins, are rarely used in impregnating insulating varnishes.

In formulating impregnating insulating varnishes it is necessary to consider not only the effect on the strength of the fabric of the original ingredients of the varnish, but the effect of its decomposition products, which are likely to be eliminated during the process of drying. In practice these decomposition products are oftentimes found to be much more destructive to textile filaments than the original ingredients. Considerable research on this aspect of the subject has been done in recent years by the British Cotton Industry Research Association and others, on the effect of oxidisable impregnating varnishes on cotton cloths. Although many impregnating varnishes are highly polymerised products, and their subsequent drying process as films on cloth involves chiefly, further polymerisation until solidification is complete, if they contain any unsaturated vegetable drying oil or the constituent fatty acids, some oxidation is bound to take place. This means that destructive decomposition products are sure to be eliminated, so that the work which has been conducted on oxidisable varnishes is not, by any means, out of step with modern practice.

It appears that the decomposition product which causes most trouble is hydrogen peroxide. Evidence has been produced to demonstrate that traces of copper and certain other metals, either present initially in the unimpregnated textile support or in the varnish, have an important influence in causing degradation, and their influence may be connected in some way with the liberation of hydrogen peroxide. There is still, however, some controversy over the precise rôle which these metals play in causing loss of strength, and the matter is not, as yet, completely explained.

Traces of copper and the other metals are probably introduced with the textile support by way of the size, which is sometimes prepared in copper pans, or by way of the varnish, which similarly is quite likely to have been manufactured in copper pots and/or in contact with a brass-cased thermometer.

When varnished cloths are first prepared it is not only the

composition of the varnish which may cause a reduction of strength, but the actual processing conditions used by the proofer in converting the liquid varnish into a dry condition. With the exception of glass silks, all the textile supports used for varnished cloths are sensitive to exposure to elevated temperatures—temperatures of the order of those used in normal proofing processes if above about 280° F. Many proofing towers are maintained within the range 250°–280° F., and these temperatures are prone to cause reductions in strength. The extent to which this occurs is governed by the time of exposure to the temperatures, and it is common practice to reduce the time of exposure as the drying temperature increases.

The reduction in strength which normally occurs under these conditions is not so pronounced with varnished cloths as with the unimpregnated cloths, for in the case of the former the threads of the cloth are at least partly protected against atmospheric oxidation by the envelope of varnish which surrounds them.

It is known that under whatever conditions oxidisable varnishes dry, degradation products are evolved, and it is reasonable to suppose that their disintegrating action on textile threads increases with temperature.

It is important, therefore, that the proofer, in drying a varnish, does not subject it to a high temperature longer than is absolutely necessary to effect solidification of the varnish, for the textile support is likely to lose strength, both as a result of natural decomposition at high temperature, and because of the acceleration of the disintegrating action of oxidation products. Of course, in the main, the proofer will see to it that the varnished cloth is not in the heated tower too long, for his production is wholly dependent on the rate at which the varnished cloth leaves the tower. Similarly he will not deliberately use an excessive temperature because heat costs money.

Varnished cloths may be quite satisfactory for strength when they first emerge from the tower, or for a few hours or even days afterwards, but this is no guarantee that they will retain their strength indefinitely. It is, in fact, quite common for varnished cloth to diminish in strength on storage, and it is the aim of every varnish formulator to devise a varnish which remains inert to storage conditions, and which has the least effect on the cloth.

The degree to which varnished cloths deteriorate in strength on storage depends upon the severity of the storage conditions. At normal temperature and humidity the oxidation process of the varnish film continues, and hence the longer the storage the

greater the loss in strength will be. This is especially true of viscose base materials and other textiles also. But if the storage temperature and humidity are increased, considerable disintegration of the varnish film is possible. In bad cases the varnish film may liquefy. Liquefaction of the varnish film is often accompanied by a serious loss of strength of the textile support. Less profound disintegration is evidenced by an appreciable development of tackiness of the varnish film, but this tackiness is only a forerunner of ultimate liquefaction. The combined influence of high atmospheric temperature and high humidity is so powerful that few products of a varnish nature can withstand it indefinitely. Where electrical equipment is to be sent to humid tropical climates serious thought must be given to the stability of the insulating varnish used for impregnating the textile supports. It is this which controls the permanence of the insulating property of a varnished cloth. If components are to be fabricated under such climatic conditions, the varnished cloth may have deteriorated to such an extent on storage there, that it is impossible to handle it without tearing because of loss of strength.

Loss of mechanical strength with partial liquefaction is accompanied by loss of dielectric strength also. The stability of varnished cloth under humid tropical conditions is therefore of importance if electrical failures are to be avoided. Components which are fabricated and tested under more ideal atmospheric conditions, such as those prevailing in the United Kingdom, may be found eminently satisfactory there, but the insulation of the same components exposed to humid conditions abroad later might easily fail.

Very special consideration has been given to this question of stability of varnished cloths under bad storage conditions, and workers like Milligan (16) may be classed as pioneers on this subject. The work they have done has enabled really stable insulating varnished cloths to be produced. Insulating varnishes are designed nowadays specifically for use on cloths for tropical conditions, and the proofer can greatly increase the resistance to deterioration by stoving his product at the highest temperature which is convenient, bearing in mind, of course, defects which high temperatures are likely to cause. It is much easier to produce a varnished cloth, really stable to tropical conditions, if a drying temperature in the range 250°–280° F. is used, in preference to temperatures in the lower range of 180°–210° F.

Thus if a high drying temperature is chosen which does not

cause a loss of mechanical strength when the varnished cloth is first produced, the resultant cloth will retain its strength under bad storage conditions better than cloths dried at lower temperatures. Tests have not yet been included for stability of varnished cloths under tropical conditions in official electrical specifications, but with the coming export drives this is a matter which we cannot afford to overlook.

Very simple tests for retention of tensile strength under warm humid conditions can be easily and satisfactorily conducted using the test conditions as laid down in Specification T.C. 200—1940, Type III, for oilskin clothing for tropical conditions, and the actual test methods are described in Chapter IX. If desired the severity of the test conditions can be increased beyond those stipulated.

Components which include varnished cloth in their make-up frequently operate at temperatures greatly in excess of those of the normal atmosphere. Thus, in effect, the varnished cloth is exposed to a further stoving of ever-increasing duration. Most insulating varnishes are not sufficiently stable to resist these higher temperatures indefinitely, and a gradual degradation of the varnish takes place. The degradation products have the effect of destroying the strength of the textile support, which in most cases is not particularly resistant to elevated temperatures for long periods of time. The degradation which occurs at elevated temperatures is comparable with the loss of strength which occurs under reasonable storage conditions, except that the degradation process is greatly accelerated.

The loss of strength of varnished cloths at temperatures which they are likely to encounter in practice, is controlled by clauses in specifications which require bursting strength or other determinations to be done on test pieces previously exposed to temperatures of the order of 110° C. for twenty-four hours or so. For varnished cloths based on glass fabric, specially designed for components operating at very high temperatures, the test conditions are suitably adjusted to accommodate the exaggerated working conditions.

Tackiness of Varnished Cloths

All varnish films, irrespective of the surface on which they are applied, dry with some residual tack. The actual degree of surface tack depends upon the natural characteristics of the varnish and on the extent to which the drying has progressed.

Excessive tackiness may therefore be an outward indication

that the varnish on a varnished cloth is in an incompletely dried condition. Incompletely dried varnishes usually possess low dielectric strengths; poor water resistance, which means a low dielectric strength under humid conditions; and poor resistance to deterioration on storage under moist conditions; with which is coupled the possibility of serious loss of mechanical strength during such storage.

A varnished cloth with pronounced surface tackiness should not be rejected out of hand as valueless; it should merely be placed under suspicion, for there is at least one varnish drying oil with excellent properties which, even when thoroughly dry, usually has a pronounced residual surface tack. The oil in question is dehydrated castor oil.

On the other hand, of course, it is quite a simple matter to disguise the excessive tackiness of a poor quality incompletely dried varnished cloth, by the introduction of lubricants into the impregnating varnish. Freedom from tack, therefore, is not an infallible indication of a first-class well-dried varnished cloth.

There are, moreover, varnished cloths which are specially designed to possess tacky and adhesive surfaces, but their tackiness is not obtained at the expense of other essential properties. A slight residual tack on varnished tape is often regarded as an advantage when the tape is required for lapping round components, for the adhesiveness keeps the tape securely in place. There is a brand of varnished silk, used for rolling into short lengths of sleeving, which possesses slight residual tack, or "cling," as it is sometimes called. This "cling" is essential, for the silk is cut into short rectangular strips which are wound lengthwise round a mandrel. The adhesion between the adjacent surfaces must be such that when the mandrel is removed, the hollow cylinder of varnished silk retains its cylindrical shape without unravelling.

Varnished cloths possessing considerable adhesive, on both or one side only, are used in large quantities, as adhesive tapes. The type with adhesive properties on both sides is made from an impregnating insulating varnish which in itself is designed to have a strong residual tack when dry. The varnished cloth which is tacky on one side only is made by applying an adhesive varnish to one side of an ordinary varnished cloth. In this instance the electrical properties of the product are provided mainly by the base varnished cloth—the final facing coat has really no other function but to provide the necessary adhesion.

It is quite a difficult problem to evolve an adhesive varnished cloth which will remain permanently adhesive. Obviously it is useless to use materials which possess excellent adhesion when first applied, but which on storage become relatively tack-free. Official specifications for adhesive varnished cloths are, the authors believe, in the process of formulation, and it is a fairly safe prophecy to make that they will include a clause governing the retention of adhesive properties on ageing. At present a prolonged heating test is used to assess this property. A very severe test is to expose an adhesive cloth to about 100° C. for twenty-four hours. This is most searching and it is amazing how few varnish constituents will withstand these conditions without alteration. The object of the test is to compress into a few hours the oxidation effect of weeks or months of storage. Whilst it is difficult to suggest a better alternative accelerated ageing test it must be borne in mind that the present accepted heating test, described above, is open to criticism. It is by no means certain that the adhesive varnish will not be based on constituents with thermosetting properties, and if this proves to be the case, heating will cause them to thermoset and all trace of adhesiveness will disappear. Under normal conditions of atmospheric temperature, however, it is highly probable that the adhesiveness would be maintained almost indefinitely. A good adhesive varnished cloth might be easily but wrongly rejected as useless.

If the cloth has only one adhesive surface the nature of the adhesive property must be such that when the cloth is in the form of a roll, it must permit unrolling without the adhesive varnish becoming detached from its proper surface and transferring itself to the plain back surface of the cloth touching it. If the adhesive varnish is removed by the back surface, the stickiness on both sides of the cloth will make it difficult to handle.

The quality of adhesiveness of single-sided adhesive cloth is often quite different from that of the double-sided material. Sometimes the single-sided adhesive material is designed with very strong adhesion, but the double-sided adhesive material has much milder adhesive properties. The double-sided material is produced by making adjustments in the original impregnating varnish itself, and not by the final application of a special adhesive varnish. Hence the slight tack on both sides of the cloth is not enough to cause difficulties in application.

The actual measurement of surface tack or adhesiveness of varnished cloths is possible by determining the force necessary to

separate two sticky surfaces. A simple means of doing this is described in Chapter IX, and consists essentially in cutting out rectangular strips of varnished cloth of identical size and placing the surfaces, whose degree of tack is required, together. A rectangular block of metal, the same width as the specimens of cloth, is placed on the strips so that it covers about half their area. Thus the tacky surfaces are pressed together by a standard load for any convenient time, and at any suitable temperature. The weight is then removed, and an attempt made to separate the two strips by attaching a weight to the bottom strip and attempting to lift the whole by means of the top strip. The weight which is required to be attached to the bottom strip, to cause separation of the two strips without lifting the weight, is a measure of the degree of tack of the surfaces of the varnished cloths. The temperature chosen for the test will be controlled by the prevailing climatic conditions which the varnished cloth will encounter in practice. If the cloth is to be used under tropical conditions the temperature of the test should approximate to these conditions, and this leads on logically to another important aspect of tackiness—the variation of tackiness with temperature.

The impregnating varnishes which are used on varnished cloths should be preferably of a thermo-setting, as distinct from thermo-plastic, type. Thermo-plastic varnishes would liquefy when heated, and this would cause difficulties in several directions. Firstly, it would be impossible to apply them to cloth and dry them by the normal tower method, for the coated cloth would adhere to the top roller. Again, there would never be any assurance of presence of an electrical insulator, of constant and uniform thickness, at the elevated temperatures which are possible in certain electrical machines. The hot varnish film would flow or be squeezed out of place, and breakdowns might occur as the direct result of diminished thickness of insulator.

The possibility of meeting a varnished cloth with a thermo-plastic impregnating varnish on it is fairly remote, because it would not be so economical or easy to manufacture as the more common satisfactory types.

Whereas, however, dried impregnating varnish films are chiefly thermo-setting in character, they are not entirely so, and they exhibit varying degrees of thermo-plasticity. This is revealed in a pronounced softening, and an increase in surface tackiness, as the temperature increases. This is a point which must not be overlooked, for after storing a roll of varnished cloth at a high tem-

perature, the tackiness induced may make it impossible to unwind it without causing serious damage.

Dielectric strength tests on thermo-plastic films at high temperatures are difficult to perform, and the results are of doubtful value. Unless the electrodes are protected, the liquefied varnish adheres to them and this necessitates cleaning after each individual determination. Even if the electrodes are protected, the weight of the upper electrode pressing on the liquid film deforms it, and tends to squeeze it out at the edges, thereby reducing the effective thickness.

Varnished cloths, if stored for long periods under warm conditions of high humidity, deteriorate and tackiness develops. This is generally true of all varnished cloths if the time of such exposure is sufficiently prolonged, but it is not too much to expect that the future will provide varnished cloth made from recently developed synthetic resins, which will remain stable indefinitely.

Flexibility of Varnished Cloths

The properties of flexibility and adhesion are interconnected, and it is convenient, therefore, to consider them together. In estimating flexibility it frequently happens that adhesion is estimated either deliberately or accidentally, simultaneously.

The adhesion under consideration now, is the adhesion of the varnish film to the threads of the textile support, and is not to be confused with the surface adhesiveness or tackiness of varnished cloths.

Varnished cloths must possess sufficient flexibility to permit handling and lapping round components, and it is an advantage if the flexibility is sufficient to allow the cloth to settle snugly into place. The flexibility of a varnished cloth is the sum of the flexibilities of its two components—the textile support and the impregnating varnish. Using the same impregnating varnish it is possible to produce varnished cloths differing widely in flexibility, according to the type of the textile support on which it is applied. For cloths of the same composition the flexibility will diminish as the thickness of the textile support increases.

Natural and artificial silks yield very flexible insulating cloths, but glass-woven and cotton-base cloths are noticeably less flexible. Varnished cloths incorporating calendered cotton fabric, which is often heavily starched, are the least flexible of all.

Although the natural flexibility of the textile support has an

important influence on the flexibility of the ultimate varnished cloth, it is the flexibility of the impregnating varnish which has, by far, the greatest influence. It is possible to formulate impregnating varnishes which give very rigid cloths—they may be made as hard and as friable as wafers.

Such rigidity makes a cloth valueless as a flexible insulator, for any attempt at lapping causes fractures of the varnish film.

Varnished cloths, therefore, must be flexible enough to withstand all the handling required in the fabrication of electrical components without fracturing. There is not, as yet, any unanimity of opinion upon the precise degree of flexibility required, and it is rarely specified at all.

Moreover, it is not only the initial flexibility of a varnished cloth which is important, but the flexibility after ageing. If a varnished cloth on mere atmospheric ageing demonstrates embrittlement, it follows that any movement inside a component—expansional or otherwise—during service, is likely to cause fractures in it. Since most impregnating varnishes, whether black or clear, contain oxidisable constituents, embrittlement on ageing is almost certain to take place to some extent. This tendency to embrittlement is accelerated at elevated operational temperatures.

The recent demand for varnished cloths based on glass silk for resisting unusually high temperatures, has brought this question of embrittlement on ageing well to the fore. Most ordinary impregnating varnishes, black and clear, become so brittle after a test period of 100 hours at 150° C. that it is impossible to bend the varnished cloths produced therefrom. The embrittlement of the varnish film causes even heat resistant glass silks to fail under this test.

There are several distinct methods of estimating flexibility and adhesion. One method is to bend the cloth round a mandrel which may be of any size from about $\frac{1}{8}$ inch upwards according to the severity of the test which it is desired to apply. In their normal state varnished cloths pass this test without showing any signs of cracking, almost without exception. The test, however, becomes quite stringent when it is used as a method of assessing embrittlement or ageing, especially for high-temperature cloths subjected to 150° C. or higher for many hours.

It is sometimes enlightening to examine both the inside and the outside of the bends produced on the varnished cloth by the mandrel test, for the outside bend gives information on the effect

of a tensile force and the inside bend information on the effect of a compressive force. This test may be developed as a means of measuring adhesion also, if 180° bends round a mandrel in reverse directions are performed several times in quick succession.

The adhesion of dried varnished films on textile supports is important, for if the cloth is folded or flexed in use it should resist such treatment without betraying signs of failure through lack of adhesion.

Resistance to film disintegration by folding or creasing depends on many factors, among which may be included the adhesion of the dried varnish to the textile threads, which may be bone-dry or contain adsorbed moisture, and traces of size or lubricant; the intrinsic mechanical strength of the varnish film itself—some films have poor strength and are crumbly, others are strong and tough; and the flexibility and strength of the textile support. The adhesion of the varnish film to a textile support will also depend to an appreciable extent on the degree of penetration of the varnish into the interstices between individual filaments which make up the threads; a thoroughly impregnated thread implies that deep seated anchors of dried varnish are sent well into the threads and serve to keep the varnish film securely in place. Penetration, in turn, depends upon the natural penetrating properties of the varnish, the care taken in its application to the cloth, the degree of twist of the threads, and the effectiveness of the scouring operation to remove size.

A very searching test for resistance to mechanical disintegration is based on a simple exaggeration of the mandrel test. The varnished cloths are folded through an angle of 180° until the two surfaces facing each other are in contact, and the finger is then lightly rubbed along the extreme edge of the fold. This is equivalent to bending the cloth round a mandrel of very small diameter. In order to avoid personal errors a specific load may be placed at the edge of the fold for a standard period of time. Film disintegration is evidenced by a permanent or semi-permanent white line which remains when the cloth is unfolded again. The properties of the textile support greatly influence the results, and with grades of glass silk at present available it is difficult to manufacture a varnished cloth which will pass this test without damage. The photomicrograph in Fig. 89 shows the effect of folding a piece of varnished glass silk.

An extreme development of this test, which very few varnished cloths will pass, is a double-fold test. The cloth is folded as

described above, and then folded over itself again, but at right angles to the first fold. Pressure is then applied at the point of intersection of the folds. The majority of varnished textiles after submission to this test show film disintegration, as evidenced by cracking, or "marking" at the point of intersection. Marking is not necessarily related to cracking. A disturbance of the varnish film in relation to fibre or yarn occurs, and marking, in these circumstances, is the visual indication of differential light refraction at the textile-varnish film interfaces.

The following supports, all impregnated with the same yellow insulating varnish and dried under the same conditions, are arranged in order of "marking," the sample with the most "marking" is placed first.

1. Glass silk (continuous fibre).
2. Nylon and cellulose acetate.
3. Calendered cotton cloth.
4. Gampi tissue paper, natural silk and viscose.

In assessing cracking or marking tendencies it should be appreciated that these will be dependent to some extent on the construction of the fabric under consideration, and on the deniers of the yarn used.

The damage on calendered cotton cloth is rather difficult to detect, but at the intersection of the folds a small continuous crack is sometimes visible which is not discernible with the other supports. To the unassisted eye the only damage visible in the other impregnated supports is white lines. The photomicrograph of the single fold in varnished glass silk gives a better impression of what the white lines really are.

Such film disintegration as described above leads to loss of insulating properties as revealed by reduced dielectric strength. Some users of varnished cloth subject it to a crushing test which consists in squeezing the cloth into a small bulk in the hand, straightening it out, and re-determining the dielectric strength. A cloth free from any disintegration does not show any diminution in dielectric insulation after this treatment.

Whenever tests for flexibility and adhesion are conducted, they should be done at controlled temperatures. Considerable differences occur at different temperatures, flexibility increasing with rise of temperature. At high altitudes, attainable by many aircraft, very low temperatures are experienced, and these reduce the flexibility of most organic materials to the state of

brittleness. Insulating cloths which are used in electrical components for aircraft should be tested therefore for adhesion and flexibility at low temperatures.

The determination of dielectric strength under mechanical tension in specifications for varnished cloth is, in effect, an attempt to measure the loss of insulating properties resulting from disintegration of the varnished film produced by an extension. In this respect it is similar to other flexibility and adhesion tests, which are based upon producing an extension in the material and noting the effect on the varnish film.

The "draping" or "handleability" of varnished cloths is conveniently measured by means of the flexometer described in Chapter IX.

The Effect of Oils on Varnished Cloths

Varnished cloths may come into accidental contact with lubricating, cleaning and cutting oils. They may also be designed for immersion in hot and cold transformer oils.

When a good grade of impregnating varnish is completely dried it attains a degree of comparative insolubility in practically all organic liquids. The highly polymerised and oxydised complexes contained in dry varnish films normally do little more than swell when left in contact with these liquids. There is rarely any case of true or complete dissolution.

Few flexible varnish films are absolutely inert to the action of organic liquids and they soften to varying extents. If excessive softening occurs, this may be permanent because of the extremely low evaporation rate of the oils from the films which have absorbed them. The danger with softened varnished cloths is, of course, that they are very easily damaged.

Generally, yellow varnished cloths are more resistant to attack by oils than black cloths, mainly for two reasons. The black colour of black varnished cloths is obtained by the use of asphaltums, bitumens and pitches, which are easily soluble in hydrocarbon oils. Although other insoluble constituents are introduced into black impregnating varnishes, the presence of these black components is a weakness, and they appreciably reduce the resistance of the black varnished cloth to oils. With yellow impregnating varnishes it is possible to select ingredients, all of which, after drying, are insoluble in oils. Secondly, the black constituents have an inhibiting effect on the drying of varnishes, and the resistance of varnish films to attack is a function of the

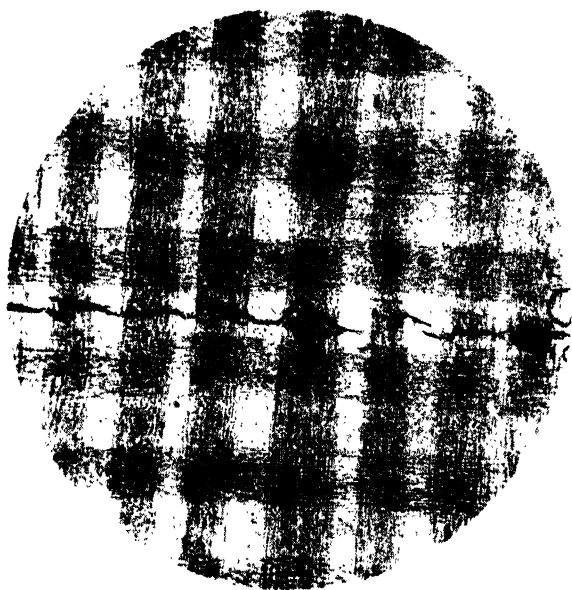


FIG. 39. Photomicrograph showing the cracked film caused by folding varnished glass silk. (Magn. $\times 40$.)



FIG. 40. Photomicrograph of transverse section through varnished calendered cloth, showing a tuft of cotton fibres protruding through four coats of varnish. (Polarised light. Magn. 90 dias.)



FIG. 41. Photomicrograph of transverse section of varnished cotton cloth showing lack of penetration by varnish between fibres.

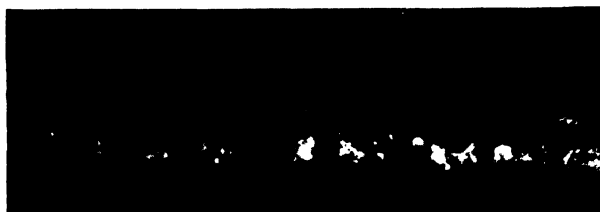


FIG. 42. Photomicrograph of transverse section of varnished natural silk showing superior penetration of varnish.

degree of dryness which they attain. There is no similar inhibition of dry with yellow impregnating varnishes, and hence, in general, they dry more thoroughly and have better oil resistance.

Resistance to oils is determined quite simply by immersing strips of the varnished cloth in the selected oil, for a period and at a temperature, likely to yield information on the performance of the cloth in practice. A common test is to immerse the strips in hot transformer oil at 100° C. or higher for periods of one hour or more. The strips are then removed, cooled, the adhering oil wiped off, and the varnish film tested for softening. Most films soften under this treatment, but if they are not easily detached from the textile base they are considered acceptable.

With black cloths, and bad cases of attack, the oil may be discoloured because of the black component in the varnish film dissolving into it.

The Effect of Chemical Reagents on Varnished Cloths

(a) **Various Chemical Reagents.** Varnished cloths encounter all sorts of chemical reagents. The components in which they are used function in factories, etc., under a wide variety of conditions.

In laundries, for example, they may be exposed to alkaline liquids, and in chemical works to acids and acid fumes.

It is a common misconception that black varnished cloth has better chemical resistance than the yellow grade, and this is based on the fact that the black constituents of impregnating varnishes are themselves chemically inert. This is, of course, quite true, but the black constituent is only a minor component of the varnish film—it may possess exceptional chemical resistance, but the rest of the constituents may be defective. Chemical resistance is, like most other valuable properties of an impregnating varnish, dependent to a large extent upon the molecular complexity of the varnish film obtained on drying, and this, as has been explained already, can be inhibited by the presence of asphaltums, bitumens or pitches. By the careful selection therefore of synthetic resins, coupled with intelligent processing, yellow varnished cloths to withstand satisfactorily almost any chemical reagent, can be produced if desired.

In the main it is easier to obtain acid resistance than alkali resistance, and by good fortune it is resistance to acidic compounds which is most frequently demanded.

(b) **Ozone.** Possibly one of the most destructive agents to varnished cloths is ozone, and this gas is frequently present in the

vicinity of electrical machines. Ozone is notoriously potent in its attack on all manner of organic insulating materials, not excluding the impregnating varnishes used in the manufacture of varnished cloths. This is an aspect of the subject which is sure to be a subject of future research, for in the past too much has been taken for granted, or neglected, because of inexperience.

Wherever air is present, the oxygen in it, under suitable electrical conditions is converted into ozone. Air naturally surrounds or envelops every machine, and provides ample raw material for conversion into ozone, for attack from the outside. But air may also be occluded in the flexible insulators themselves, as the result of incomplete penetration of impregnating varnish. In this instance attack by ozone may commence internally. The two forms of attack by ozone can combine therefore to hasten premature electrical breakdown.

The possibility of the formation of ozone inside varnished cloths is considered in greater detail in the next chapter.

The Acidity of Varnished Cloths

Sometimes purchasers of varnished cloth insist on a product with an acidity below a certain specified limit. Varnished cloths are not likely to contain strong mineral acids unless they arise from the degradation of mineral salts used in making the raw textile. Organic acids of differing molecular weights, either in the original constituents of the impregnating varnish or developed during its subsequent disintegration, are, however, nearly always present in some quantity.

The real danger of these organic acids is that they stimulate corrosion of any copper conductors with which they come into contact, and the most potent in this respect are the acids of low molecular weight.

The acids which are most commonly present in varnish films are formic, acetic, propionic and possibly butyric, all of which are formed as the direct result of oxidation of the varnish film. Other free acids such as oleic, stearic, palmitic and the fatty acids of vegetable drying oils, may be present in small amounts in the original oil. Abietic, phthalic, and maleic acids may be contained in the resinous components of the varnishes.

There is a tendency to be misled over the acidity of varnished cloths, for the acidity depends upon their age and storage conditions. A cloth may be accepted initially which on ageing becomes rapidly acidic.

Unfortunately it is a difficult matter to determine the acidity of a varnished cloth accurately. Soluble acids near the surfaces of the varnished cloth can be washed out fairly easily, but the acidity of the cloth is by no means confined to the outer surfaces of the varnish layer—it is distributed throughout the mass of the film. It is, nevertheless, very probable, that since oxidation is most pronounced at the surfaces, most of the oxidation products, including acids, are congregated there. However, to obtain an accurate idea of the acidity of a varnished cloth the acids should be extracted from it completely. This is not easy because of the insolubility of polymerised and oxidised films.

Probably the only way of obtaining a true estimate of the acidity is to cut a section of varnished cloth into tiny pieces, and to extract them with a suitable solvent under reflux for several hours.

The general procedure is to extract a portion of cloth with cold or boiling distilled water and to test the resultant aqueous solution for its pH value. Further details of this method are given in Chapter IX. The acidity obtained by this treatment is only a measure of the water soluble acids present, and does not take into account organic acids of higher molecular weight.

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CHAPTER VIII

THE IMPREGNATION OF TEXTILE SUPPORTS WITH SPECIAL REFERENCE TO OCCLUSION OF AIR

THE presence of air in an insulator is a serious disadvantage.

It is a notoriously bad conductor of heat. The passage of an electric current through electrical components often generates a considerable amount of heat, and if harm to the component is to be avoided this heat must be dissipated rapidly to avoid an excessive increase in temperature. Elevated temperatures, in turn, promote carbonisation of the insulating medium or varnish, and electrical breakdown ultimately follows. Both the support for the impregnating varnish, whether it is cotton or natural or artificial silk, and the impregnating varnish itself, carbonize readily at comparatively low temperatures. Air, in fact performs three rôles, firstly, because of its low heat conductivity, and secondly, because it provides oxygen to assist disintegration by combustion.

Wherever air pockets occur, therefore, local hot spots are liable to develop and destruction of the insulator takes place at these points. The ideal insulator is one which is entirely homogeneous and free of occluded air.

Thirdly, air is ionisable under the varying electrical stresses met with in practice, with the consequent production of ozone and oxides of nitrogen. The disruptive effect of oxides of nitrogen and ozone on organic materials, with loss of insulating properties, is well known and need not be elaborated. Experimental work has been recorded by Fessenden, Perrine (1), Dawes, Hoover and Whitehead (2), Shanklin and Matson (3), and others. High voltages are necessary to cause ionisation of air, and if these are not designed to be present with a particular electrical machine, they may be caused accidentally by switching off normal contactors. In a recent paper by Taylor and Randall (4), it has been shown that voltages up to twenty times the line voltage may occur when normal conductors are switched off. The presence of air coupled with a high voltage conspire together to cause electrical breakdown.

The efficiency of saturation of the textile support with impregnating varnish must be considered, therefore, in the light of the possible occlusion of air, and for other reasons also. If, for example, cotton is the support, this is very susceptible to the

influence of moisture and water vapour, in the raw state. On the other hand expertly formulated impregnating varnishes applied correctly and thoroughly, have exceptional water resistance, and water absorptions representing a fractional percentage only are easy to achieve. It follows from this that the maintenance of good electrical properties of insulators with a cotton or similar supports under humid conditions is controlled to a large extent by the efficiency of impregnation. The photomicrograph of Fig. 40 shows cotton fibres protruding through the varnish film on varnished cloth. If these fibres are not completely impregnated with varnish, water may be conducted well into the fabric itself, and the effective thickness for insulation considerably reduced.

With the foregoing factors in mind, an investigation was instituted to ascertain the quality of the flexible insulators now available on the market, in the first instance, with special reference to occluded air.

A sample of varnished cotton cloth was selected at random and a section subjected to a microscopical examination. A very bad feature in its construction was immediately revealed, in that there was an almost complete lack of varnish in the interstices between the fibres of the fabric.

The uses to which varnished cloth is put dictate that it should be as homogeneous in construction as possible. It will be appreciated, therefore, that if a varnished cloth is composed of two layers of impregnant, sandwiching a mixed interlayer of cotton fibres, starch or other dressing and air, the effectiveness of this material as a reliable electrical insulator is open to grave suspicion. This criticism is justifiably applicable to a good deal, but not all, of the varnished cotton cloth produced to-day.

Photomicrographs taken under conditions of dark ground illumination, see Figs. 41 and 42, illustrate the deficiency of impregnation of an impregnated cotton cloth, and the improvements obtainable with impregnated natural silk.

One is a section of varnished cotton cloth treated with two coats of impregnating varnish. The film of impregnating varnish is not easily detected for it is absorbed in the dark background. If the transverse sections of the yarn (A and A¹) are examined, and if all black opaque background visible therein is credited as varnish, it is obvious that there is an almost complete absence of varnish in the interstices between the individual cotton fibres comprising the yarn. The sections of yarn stand out as brilliant white woolly masses with sharply defined edges. If impregnations

were perfect the sections A and A¹ would be either greyish and not white, or would have practically disappeared into the dark background. All edges would be blurred also.

All this is further confirmed by an examination of the photomicrograph of varnished natural silk, where the sections of the yarn are very blurred and indistinct.

In direct antithesis to varnished cotton cloth, varnished natural silk is a much superior insulating material. The whole section is more nearly submerged into the dark background, and edges of the yarn are very indistinct, thus indicating considerably improved impregnation.

Photomicrographs, Figs. 43 and 44, represent plan views of the same specimens of varnished cloth and varnished natural silk respectively. The cotton cloth again stands out brilliant white and substantially unimpregnated, whereas the silk is impregnated so well that it is only just distinguishable from the background. The occasional white spots in the photomicrograph are foreign bodies embedded in the impregnant.

If a fabric is not completely impregnated then spaces free of impregnant must be present, and the substance occupying these spaces must be air or some other gas or vapour, and from a consideration of the photomicrographs its volume is substantial.

Another factor which must be considered in connection with cotton cloth is the structure of individual fibres or filaments. Cotton fibres are of tubular construction, whereas those of natural silks and rayons, such as viscose and cuprammonium, are solid. This means that in the case of cotton, not only is it necessary to saturate the interstices between individual fibres, but ideally, the interior of the fibres also, which is a much more difficult proposition.

This is amply demonstrated in photomicrograph of Fig. 45, which represents an individual filament of cotton. Air bubbles at B, inside the cotton fibre, are plainly visible. No air bubbles are possible in the natural silk filament because of its solidity, and this applies equally to artificial silk filaments and glass filaments, which are also of solid construction. Reference again to Fig. 41 clearly shows the sausage-shaped cotton fibre sections, and the difficulty of forcing impregnating varnish into these constricted cavities is readily appreciated. This process would seem to be practically impossible if application of the varnish by mere immersion is used.

During a consideration of the sectional form of filaments those



FIG. 43. Photomicrograph of plan view of varnished cotton cloth showing lack of penetration of varnish between fibres.

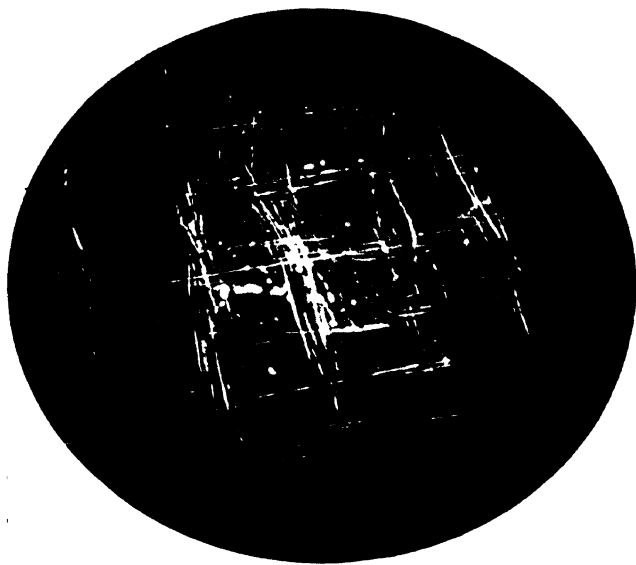


FIG. 44. Photomicrograph of plan view of varnished natural silk showing superior penetration of varnish.

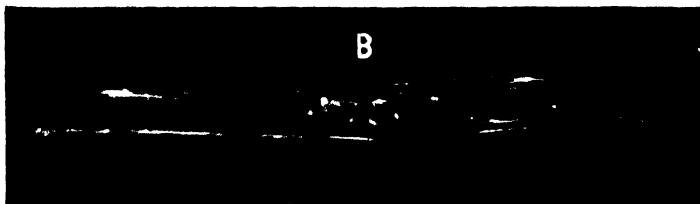


FIG. 45. Photomicrograph of a cotton fibre taken from varnished cotton cloth, showing bubbles inside the hollow portion at B.



FIG. 46. Photomicrograph of calendered cotton cloth, teased out at edge. Black blobs, clinging to the fibres are particles of starch.

of the rayons must be considered also. Cuprammonium is either smooth circular or oval in shape, whereas viscose is very irregular. Its perimeter undulates with deep channels and high smooth peaks. The channels are of such small dimensions that some difficulty will be encountered in making impregnating varnish displace air from them, and for this reason cuprammonium silk would appear to be a better support for a varnished cloth than viscose, because it is free of such surface irregularities.

With the calendered cotton cloth, normally used for the production of insulating cloth, a further factor which militates against satisfactory impregnation is the fact that the cloth has been starched and squeezed between rollers. The application of pressure has the effect of bedding the fibres tightly on to each other, and they are prevented from springing apart, being bound together by starch or other size. This very close packing makes it even more difficult for the impregnant to find its way into all the interstices of the yarn and the cloth. It is possible, of course, that calendering may flatten out some of the hollow cotton fibres, but it is not feasible that all of them would be treated thus. It is not improbable that some would be partly constricted, and this would make impregnation even more difficult.

There is another factor which influences the ease and degree of penetration of the yarn in cloths, and it is the number of twists per unit length of yarn. The greater the number of twists per unit length or, in other words, the tighter the yarn is twisted, the more difficult it will be for the impregnant to disappear into its interstices. The effect of twist on penetration is considered in more detail later.

Finally, the last important factor to study is the effectiveness of the sizing process for warp yarns. If the ultimate fabric is scoured completely free of size before it is used as the basis for a flexible insulator, then the efficiency of the sizing process is immaterial, for all the size applied initially will be washed out and the yarn will be left in its original raw untreated condition. But very few scouring operations attain this degree of efficiency and traces of size are generally left behind.

Sizing is an essential part of textile manufacture. There is more than one way to consider the sizing of threads. Scouring to remove size completely, when the size has fulfilled its primary rôle is a difficult process, and it may be argued reasonably that if the minimum amount of size necessary for weaving were used and arranged so that it remained substantially on the exterior of the

yarn, it could be removed more readily by scouring. The cloth would be left free of size contaminant and ready to receive the impregnating varnish. This, in fact, is the ideal procedure. If, however, scouring is not effective, odd amounts of size remain distributed between the interstices of the fibres or filaments and make the subsequent impregnation by varnish more difficult ; and after all, it is the varnish which is the electrical insulator and not the size.

If scouring cannot be done efficiently then it is probably better to aim at thorough impregnation by size, in order to eliminate air pockets as much as possible, and to apply varnish with or without scouring. If inefficient scouring were used on a well-sized cloth, some size would be removed from the outside of the yarns, but the residue would be left inside substantially intact, and would thus act as a seal against further ingress of air. Application of varnish over this would then produce a solid uniform whole free of occluded air. This is still, however, a poor substitute for the product obtained from a well-scoured cloth thoroughly impregnated by varnish.

The starching process as used for calendered cloth for insulating purposes is especially suspect. Starch itself is gelatinous by nature and possesses very poor penetrating properties. It is in fact primarily used to give a smooth even surface, without regard for penetration. The final result is a fabric containing much entrapped air, and, at the same time, the starch seal militates against penetration of impregnating varnish. Photomicrograph of Fig. 46 illustrates a piece of ordinary raw calendered cotton insulating cloth. The edge has been teased out with a blade, and agglomerates of starch or similar material can be seen adhering tenaciously to the outside of cotton fibres. It is at once realised the pronounced effect that such relatively large amounts of starch, etc., must have on the ease and completeness of impregnation.

Investigation into the Impregnation of Fabrics. The usual method adopted for the impregnation of cotton and silk fabrics is described in detail in Chapter V. Initial experiments were conducted, therefore, using parallel conditions, and the results obtained were carefully examined. It was considered advisable to conduct the investigation on the simplest convenient component of the fabric—the yarn—and the materials chosen were cuprammonium and viscose rayon. Under more favourable conditions natural silk would have been used, but it has been in such short supply, and much work has been done already to substitute it by artificial

silk for various purposes, it was thought that experimental conclusions on artificial silk would probably be of more value in the future. Cuprammonium rayon was chosen initially instead of viscose, solely because its use would appear to eliminate any complications arising from surface irregularities. There are, however, many properties which the ideal varnished rayon should possess, and in general, viscose appears to satisfy these requirements better than cuprammonium rayon.

Obviously the natural wettability of cuprammonium rayon filament has an important influence on the spreading and penetration of an impregnant into yarn produced from it. The most fundamental way of ascertaining this is to apply impregnating varnish directly to individual filaments, but practical difficulties precluded this procedure. Moreover, since individual filaments do not exist as such in fabrics, but are twisted together to form the yarn, the work was conducted as indicated above, on the yarn.

It is not common practice to take special precautions to ensure perfect impregnation of cotton or silk fabrics during the production of varnished cloths and silks. Only too often perfect penetration is assumed. The fabric is passed slowly through a bath containing impregnating varnish and then into a heated zone to dry it. With some proofers insufficient consideration is given to the efficiency of impregnation, for they are pre-occupied primarily in adjusting conditions to give the maximum output in a given time. Their cry is always for varnishes which dry rapidly so that they can be sent through the heated zone at ever-increasing speeds. In this desire for increased output, rarely is thought given to the consequential effects on penetration. Visual examination of the varnished cloth by the naked eye is not always a true guide to the extent of penetration, and may be misleading.

The first experiments were conducted on short lengths of cuprammonium yarn, containing some lubricant, as used for weaving, and these were dipped into impregnating varnish thinned with white spirit to normal dipping consistency. After thirty seconds immersion the specimens were withdrawn, allowed to drain for five minutes, and then suspended in a heated stove at 280° F. for one hour. The bulk of varnished cloth produced has a treatment little more elaborate than this.

In order to cover most of the constituents used in impregnants, and thus avoid dogmatic generalisations without sufficient evidence, lengths of cuprammonium yarn were dipped into fifteen

different types of impregnating varnish, in which treated drying oils constituted the major components.

Subsequent microscopical examination revealed that in every case very large numbers of bubbles were left distributed in the yarn. The photomicrographs opposite demonstrate conclusively the existence of these bubbles, which orientate themselves in parallel chains in the direction of the filament lengths, and in the direction of draining. Small bubbles are nearly spherical and the larger bubbles are sausage shape.

As a rule the shape of the bubbles is very regular, but sometimes, if a bubble is encountered whose shape is irregular, this is possibly due to the presence of excessive lubricant on the surface of the yarn filaments. These deformed bubbles are, however, negligibly few.

Photomicrographs of Figs. 50 and 51 also show the presence of parallel chains of bubbles in specimens of varnished cuprammonium silks.

An attempt was made to count the number of bubbles in a unit length of yarn, and if possible to compute, by calculation, the actual volume of the yarn occupied by them. To obtain an accurate measurement of the total number of bubbles is a formidable and almost impossible task, for often chains of bubbles are encountered where the bubbles become progressively smaller, finally dwindling away beyond the range of available optical detection. It was decided that wherever the resolution of a Watson Parachromatic quarter-inch objective, with an X5 Huygenian eyepiece under critical illumination, was sufficient to separate two in a chain, then each bubble was counted as one. The method of counting was to count the number in each half millimetre of yarn, with the aid of a micrometer eyepiece, take the average of ten such counts, and multiply the result by twenty to give the number of bubbles per centimetre. The ultimate number was the average of three determinations on three separate lengths of yarn, impregnated simultaneously.

The size of the bubbles varied from about one micron in diameter for the spherical ones, to several hundred microns for the length of the sausage shape type.

Table 85 shows the average number of bubbles per centimetre, and gives an idea of the possible extent of this unsatisfactory condition in yarns of a varnished cloth. Table 86 shows the effect of introducing solid particles in the form of pigment or dyestuff into impregnating varnishes. The figures in this table were

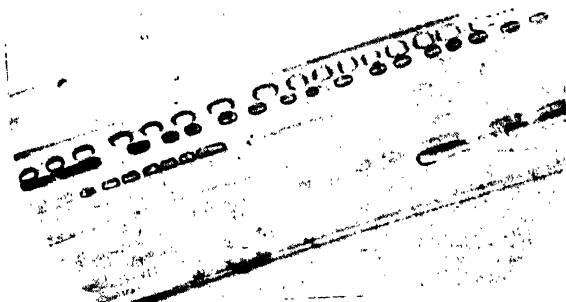
Cuprammonium yarn incompletely impregnated with varnish,
showing air bubbles.



FIG. 47



FIG. 48



Varnished cuprammonium silk showing bubbles.



FIG. 50

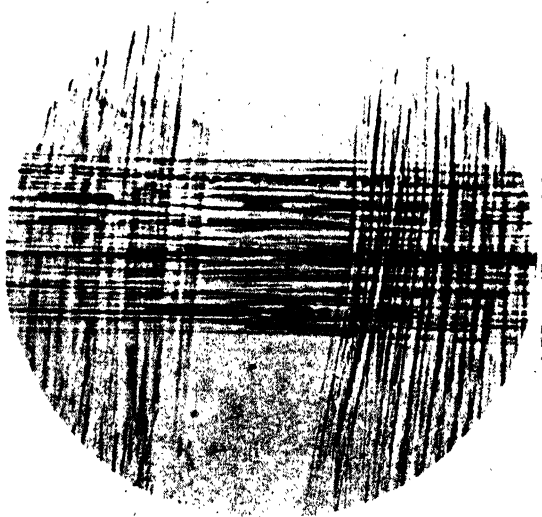


FIG. 51. (Magn. 280 dias.)

[To face p. 153.]

obtained with the same impregnating varnishes as those used for the previous experiments, except that 1·8 per cent. monastral blue was added. The effect of the presence of solid particles was discovered quite accidentally, for monastral blue was finely dispersed in the varnishes, originally, merely as an aid to see, under the microscope, precisely where the varnish had penetrated.

These tables show the astounding number of bubbles present even in one centimetre of a single yarn. With the exception of impregnant 1B all the impregnants of Table 36 containing monastral blue show a substantially increased number of bubbles, and it would appear most inadvisable for this reason alone to include any solid colouring matter in impregnating varnishes.

The tables also show quite conclusively that normal methods of application of impregnating varnish are unsatisfactory, and that irrespective of the composition of the varnish the trouble is present in a large degree. The composition of the varnish is obviously an important factor in inducing this phenomenon, for figures varying from 80 to 960 are possible with different types of impregnating varnish.

The cuprammonium yarn used for these experiments contained a certain amount of lubricant of unknown type, and it is possible that this may have exerted some influence on the efficiency of impregnation.

Table 35

Impregnant	Average Number of Bubbles per cm. of Yarn
1	960
2	452
3	280
4	384
5	120
6	80
7	500
8	500
9	180
10	580
11	560
12	180
13	420
14	800
15	220

Table 36

Impregnant *	Average Number of Bubbles per cm. of Yarn
1B	732
2B	974
3B	958
4B	1,280
5B	800

* These impregnants are exactly as those of Table 35 except that 1.8 per cent. of monastral blue was incorporated. The applications for the results of Tables 35 and 36 were made under identical conditions, at the same time, and are therefore strictly comparable.

Even if the final fabric is scoured before impregnation it is not certain that all the lubricant will be removed, and if it is a contributory cause of bubble formation a certain amount of this trouble may still be caused by it.

The most satisfactory method of assessing bubble formation is to measure the actual volume of bubbles as against volume of yarn. Because of the considerable variation in size and shape of the bubbles it is, in practice, an almost impossible task to decide upon a fair average figure for bubble volume for calculation purposes, and it was decided to accept the total number of bubbles as a rough guide to the efficiency of impregnation. The results of all experiments are reported on this basis. The series of experiments recorded on Table 35 was repeated on a separate occasion, and the results are recorded in Table 37. The two sets of results compare favourably, and indicate the extent to which reliance can be placed on bubble counts.

On the whole the results for comparative purposes with different impregnating varnishes are valuable, and the numbers of bubbles are generally in the same ratio, although not necessarily of the same magnitude.

Surface Tension and Efficiency of Impregnation. It was noticed that the surfaces of the impregnated yarns varied because of irregularity of the film of impregnating varnish, and an attempt was made to correlate this readily accessible surface condition with bubble formation. It was considered that surface tension and/or interfacial tension must play an important rôle in impregnation, for on them depends the ease of wettability of the yarn.

Table 37

Impregnant	Average Number of Bubbles per cm. of Yarn
1	620
2	140
3	200
4	100
5	80
6	40
7	320
8	280
9	190
10	240
11	480
12	980
13	300
14	600
15	220

The part which surface or interfacial tensions play is extremely complex. There is the interfacial tension between varnish and air, the material of the yarn, water or moist yarn, and lubricant in yarn. All yarn naturally contains a certain amount of moisture and this influences wettability.

There are many other complicating factors, for the interfacial tensions are altering throughout the drying process of the varnish, by reason of the increase in temperature. This applies to interfacial tensions involving air, water, lubricant and impregnating varnish. But the elevated temperature also brings about profound changes in the constitution of the varnish. Firstly, the volatile component is distilled off gradually, until ultimately it has all disappeared, and then the non-volatile residue polymerises and oxidises, processes which seriously affect physical properties.

It is not possible to make interfacial tension determinations to accommodate all these conditions, but in Table 38 the results are given of the interfacial tensions, between varnish in the condition exactly as used for impregnation, and water, at ordinary room temperature (25° C.) and also at 60° C.

The method used was devised by Gardner (5) and consists in counting the number of drops of liquid which detach themselves

from a fine capillary at the end of a U-shaped pipette. The drops or bubbles form under water and a definite volume of liquid flows out. The number of drops formed from a definite volume of liquid is inversely proportional to the interfacial tension, after taking the specific gravity of the liquid into account.

Table 38

Interfacial Tensions between Impregnating Varnish and Water

Impreg- nant	Measurements at 25° C.		Measurements at 60° C.	
	Average Number of Drops	Specific Gravity	Average Number of Drops	Specific Gravity
1	154	0.929	176	0.903
2	167	0.876	194	0.853
3	336	0.884	337	0.861
4	169	0.890	283	0.867
5	220	0.882	194	0.859
6	219	0.867	226	0.844
7	257	0.908	262	0.885
8	181	0.881	192	0.858
9	234	0.927	363	0.904
10	177	0.875	179	0.852
11	217	0.868	236	0.845
12	178	0.873	172	0.850
13	331	0.885	312	0.862
14	290	0.906	286	0.883
15	181	0.919	156	0.896

A consideration of Tables 85, 87 and 88 reveals that there is no strict relationship between the number of air bubbles in impregnated yarn, and the interfacial tension between the impregnating varnish and water. There does appear to be some rough connection in some instances, but it is obvious generally that other influences complicate the issue. This is not at all surprising when all possible influences are reviewed.

It was thought that a superficial visual examination of impregnated yarns might throw some light on the subject and provide a quick method of predicting the presence of air bubbles. The results of such a superficial examination are given in Table 89.

Neither are these results any true criteria of the efficiency of impregnation, for they do not agree with the results expressed in Tables 85 and 87.

The apparent absence of any law or order in these results at least emphasises the complexity of the mechanisms involved, but the authors were convinced of the important effects which surface

Table 39

Impregnant	Condition of Impregnated Yarn
1	Two beads per unit length of yarn. Fairly good.
2	
3	Larger beads than 1. Fair.
4	No beads. Good.
5	Number of small beads. Very fair.
6	" " " Fair.
7	Many large beads. Bad.
8	No beads. Good.
9	" " "
10	Few small beads. Fair.
11	" " " Very fair.
12	" " " " "
13	" " " Fair.
14	Very patchy film. Bad.
15	No beads. Good.

and interfacial tensions must have, and they persisted in their attempts to establish this experimentally.

Four lengths of yarn, therefore were impregnated under carefully controlled conditions, according to the following details.

1. The yarn was dried at 110° C. for four hours, and while it was still hot it was immersed in the impregnant, drained, and stoved off at 110° C. for ninety minutes. The impregnant was substantially a drying oil containing, in addition to drier, a small amount of volatile solvent. The object of this treatment was to remove, as far as possible initially, any occluded moisture in the yarn by heating; the heating process would, in all probability, cause some volatilisation of the lubricant present also, although its composition was not disclosed and this is mere conjecture. The yarn was immerse whilst still hot to preclude any chance of re-absorption of moisture.

2. The yarn in this case was treated normally by immersion in the impregnant, without previous drying to effect removal of moisture. The impregnant used was the same as in Experiment 1 except that no volatile solvent was present.

3. The yarn was treated exactly as in Experiment 2, but the impregnant was diluted with 20 per cent. of volatile solvent.

4. The impregnant used was exactly as in Experiment 1, but the yarn was impregnated without preliminary drying.

Table 40

Experiment	Number of Bubbles per cm. of Yarn
1	60
2	440
3	140
4	300

These results are in strict conformity with the theoretical conception of the mechanism of impregnation as held by the authors, and the following conclusions may be drawn. The worst result (No. 2) was obtained with an impregnant absolutely free of volatile solvent. The presence of solvent reacts favourably in two directions simultaneously; it reduces both viscosity and interfacial tension, and a reduction of these properties means improved impregnation. Conversely the absence of solvent means that interfacial tension is of a high order and that penetrating properties are of a low order, and this is proved experimentally.

Better penetration was obtained in No. 4 because there is a small amount of solvent present, and vastly improved penetration was demonstrated by No. 3, where a much larger amount of solvent is incorporated.

The best penetration of all was given in No. 1 and it demonstrates in an unmistakeable manner the importance of removing moisture and/or lubricant from the yarn before impregnation. The moisture and/or lubricant exerts a greater influence than modifications of the impregnating varnish by the addition of a petroleum hydrocarbon solvent.

The Effect of Scouring. The above results indicate that heating the yarn before impregnation results in substantially improved penetration, and this may be attributed either to volatilisation of occluded moisture, or lubricant, or both. Of course some lubricants may be only partly volatile at the drying temperature, or they may be completely non-volatile.

Experiments, therefore, were conducted on carefully scoured yarn so that the influence of the lubricant could be investigated, for scouring is the only really satisfactory way of removing all lubricant.

The yarn was boiled with a 1 per cent. solution of "Persil" for three two-hour periods; each boiling was conducted with fresh

"Persil." It was then washed in running water and finally boiled for three two-hour periods, with distilled water to make certain that all water-soluble material was removed. It was then dried at 110° C. for ninety minutes, cooled, and the whole range of impregnants 1-15, applied, and dried as in Tables 35 and 37.

Table 41

Impregnant	Average Number of Bubbles per cm. of Yarn		
	Scoured and Dried Yarn	Untreated Yarn as Table 35	Untreated Yarn as Table 37
1	40	960	620
2	146	452	140
3	220	280	200
4	160	384	100
5	0	120	80
6	0	80	40
7	60	500	320
8	60	500	280
9	120	180	190
10	100	580	240
11	140	560	480
12	80	180	980
13	40	420	300
14	80	800	600
15	180	220	220

The results in Table 41 show that scouring of the yarn followed by drying and cooling effects with most impregnants substantial improvement in penetration, in fact, with Impregnants 5 and 6 perfect penetration is obtained. The fact remains, however, that the composition of the impregnating varnish exerts a powerful influence. The removal of moisture from the yarn by heating, before application of impregnant, was not so efficient as in the experiments recorded in Table 40, and the fact that the yarn was cooled in air, also implies that a certain amount of moisture may have been reabsorbed, before immersion in the impregnating varnish could prevent it. The object of the drying process was not to completely desiccate the yarn as in Table 40, but to drive off excess water resulting from the boilings and washings. It is reasonable to assume therefore, that more satisfactory results

than those recorded in Table 41 would be obtained if the yarn were completely desiccated subsequently, and impregnated whilst still hot.

The Influence of Composition of Impregnating Varnish on Penetration. The indications are that improvements in penetrating properties can be obtained by reducing the surface or interfacial tension of the impregnating varnish.

This can be achieved by adjusting the components of both volatile and non-volatile portions. The authors have concentrated on modifications of the volatile constituents only, but they realise that the part played by the non-volatile constituents may be equally important. The former will influence penetration in the initial stages, and the latter also after the thinners or solvents have evaporated.

It was anticipated that penetration would be controlled not only by reason of the interfacial tension of the solvents, but because of their volatilities also. The solvents as used have lower surface and interfacial tensions, and lower viscosities, than the non-volatile portions of impregnating varnishes. In the first part of the drying process the solvent evaporates, and the viscosity and interfacial tension of the residue increase, although, of course, a rising temperature minimises both tendencies. If the viscosity and interfacial tension increase more rapidly than the impregnating varnish penetrates the yarn, poor impregnation results. From theoretical considerations, therefore, the use of a slowly evaporating solvent should be advantageous, since this would allow longer time for penetration. Alternatively, a prolonged soaking in the varnish before stoving might achieve the same object.

Again the non-volatile portion of the impregnant should possess as low a viscosity as possible, for after the solvents have disappeared its influence will begin to be felt in full measure.

All impregnants contain solvents to facilitate application, and assuming perfect impregnation is achieved before stoving, the loss of volatile matter subsequently causes voids or air pockets, unless the viscosity and interfacial tension of the non-volatile residue are low enough to allow the varnish residues to coalesce and flow together to form a continuous and solid film again. Alternatively, if it were possible, an impregnant free of volatile material would be a great advantage, but there are many formulation and practical difficulties in the way of achieving this. Once the impregnant was effectively in its place, it would continue to fill the space occupied initially in spite of subsequent treatment.

The results of impregnation tests, using various solvents, and combinations of solvents, are given in Table 42.

Table 42

Solvent	Average Number of Bubbles per Unit Length of Impregnated Yarn		Interfacial Tension of Solvent. Average Number of Drops at 20° C. (Inversely Proportional to Interfacial Tension)	Specific Gravity of Solvent, 20° C.
	With Impregnating Varnish			
	A	B		
White spirit . . .	640	433	145	0.798
Turpentine . . .	473	273	361	0.883
Butyl alcohol . . .	420	586	Considerably higher than 900	0.814
Butyl alcohol /1 . . .	446	326	894	0.847
Turpentine /1 . . .				
Paraffin . . .	466	186	138	0.803
Paraffin /1 . . .	380	226	445	0.841
Turpentine /1 . . .				
Tetralin . . .	473	193	27	0.967

Table 42 shows the results of experiments conducted on cuprammonium yarn, carefully scoured and dried, before impregnation with varnish. The impregnating varnishes chosen for the experiments were known to have poor impregnating properties, and they were used so that differences in degree of impregnation with various solvents would be readily apparent.

Broadly the results show, that firstly a low surface tension is essential for good penetration, and secondly that a low evaporation rate is at least equally important.

White spirit is the usual solvent or thinner used in impregnating varnishes, and the figures demonstrate that it is about the worst solvent for the purpose, if impregnation only is considered.

Turpentine has a roughly similar evaporation rate to white spirit, but a much lower interfacial tension. It should give, therefore, improved penetration, and this is shown both for impregnating Varnish A and Varnish B. With Varnish A too, the expected improved penetration is obtained with butyl alcohol, which possesses an exceptionally low interfacial tension; similarly the blended thinner—turpentine and butyl alcohol shows the anticipated intermediate result. With Varnish B, butyl alcohol shows an unexpectedly poor figure, but the blend of turpentine

and butyl alcohol shows an intermediate and improved result by comparison with that with white spirit for the same varnish.

Both sets of figures emphasise the importance of a low evaporation rate, which means a prolonged retention of a low viscosity by the impregnating varnish. For the two varnishes under consideration this actually appears to be more important than a low interfacial tension. This is particularly true with Varnish B, for although tetralin has a high interfacial tension its low volatility favours impregnation.

The Effect of the Twist in Yarn on the Penetration of Impregnating Varnishes. The following experiment was conducted in order to determine what effect the amount of twist in yarn had on the number of occluded bubbles remaining after impregnation with a varnish.

Theoretically it might be anticipated that soft spun yarns would permit easier impregnation and yield a reduced number of bubbles. On the other hand, however, tightly spun yarn, because of the reduced space between individual filaments, would be more difficult to impregnate as evidenced by an increased number of bubbles.

Regenerated cellulose yarns (80 denier), having respectively 5, 10, 20, 80 turns per inch of twist, were impregnated with two impregnants known to have imperfect penetrating properties.

No particular care was taken in cleaning the yarns, which were used exactly as received from the manufacturer. They were immersed in the varnishes and allowed to remain thus for ten minutes, and then dried off at a temperature of 280° F., for one hour.

The twists in the yarns were prevented from altering, by tying knots in the yarn, and the impregnant was applied to the knotted portion.

The bubble counts for the above series of experiments are given in the table on p. 165.

From these results it is clear that as the number of twists per inch of yarn increases, so the likelihood of trapping air increases. This seems to bring to light one important factor which influences the proper impregnation of a fabric—the twist of the yarn to be impregnated.

These results are in conformity with previous work, which indicated that natural silk fabric, on impregnation with varnish, rarely betrayed the presence of occluded air bubbles. Natural silk yarn has very little twist—usually of the order of one twist

Table 43

Details of Yarn	Number of Bubbles per Cm.
Oil A on 5 T.P.I. .	636
„ „ 10 „ .	712
„ „ 20 „ .	825
„ „ 30 „ .	980
Oil B on 5 T.P.I. .	518
„ „ 10 „ .	1,080
„ „ 20 „ .	1,784
„ „ 30 „ .	2,514

per inch—it seems that this low twist greatly facilitates impregnation.

In aiming at perfect results, therefore, it is apparent that cloth should be used, woven from yarn with the minimum amount of twist.

The Effect of Vacuum on the Impregnation of Yarn with Varnish. Soft spun viscose yarn was treated in the following manner.

Short lengths were dried at 230° F. for two hours, and then immersed immediately in the varnish, suitably thinned. A vacuum of 28 inches was then drawn and maintained for forty-five minutes, after which it was released and the lengths of yarn allowed to remain immersed for a further fifteen minutes. They were then withdrawn, allowed to drain, and dried by stoving at 230° F. for one hour. Duplicate experiments were conducted on two different types of varnish.

Table 44 below gives the results of the bubble counts from the two lengths of yarn.

Table 44

Impregnating Varnish	Bubbles per Cm. of Yarn
No. 8	828
No. 11	995

It is therefore apparent from these results that a treatment consisting of mere drying of yarn to remove moisture, followed by

vacuum impregnation, is not sufficient to ensure complete impregnation with varnish. The application of a vacuum may succeed in sucking the varnish well into the interstices between filaments, but if the surface of the filaments is not effectively wetted by the varnish, it may subsequently retreat from its original location and leave voids.

Conclusions from the Foregoing Experiments

The results indicate that it is no easy matter to effect perfect impregnation of the usual textile supports with impregnating varnish. The conditions of treatment used in the experiments were in general much better than normal production treatment. In the former, special care was taken to prepare the yarn by scouring, and pre-drying at high temperature to remove moisture, and special adjustments were made during application by the use of vacuum. Normal production treatment usually consists solely in immersion of the cloth as received from the textile manufacturer, in the varnish for a few minutes or even seconds, followed by heating. The inference is, therefore, that normal production treatment is inadequate to guarantee the best degree of impregnation with all types of textile support. But this is no reflection on the proofers, for the above experiments show how difficult it is to attain this result, always, even under laboratory conditions.

There are many factors which exert an influence on penetration of varnish and they may be summarised briefly as follows.

1. The Interfacial Tension between the Varnish and the Surface on which it is Applied. If the varnish does not "wet" this surface, other useful supplementary influences will be of no avail.

The ultimate interfacial tension is the combined effect of the natural interfacial tension between the varnish and the pure clean filament, and the interfacial tensions between varnish and absorbed and/or adsorbed moisture, lubricant, size, starch and possibly antiseptic.

One solution of the problem is to formulate an impregnating varnish which accommodates all these factors, and this will eliminate the necessity for special cleansing and drying of the textile.

Experimental results show that this can be achieved in some measure for a particular brand of filament. Tables 85 and 87 show that bubble counts per centimetre of from 80 to 960, or from 40 to 980, can be obtained by using different impregnating varnishes under the same conditions.

It is not, however, a safe policy to rely upon the formulation of an impregnating varnish which will accommodate all surface conditions.

How then can improved results be obtained? The experiments demonstrate that preliminary drying of the fabric has a beneficial effect, and that even better results can be obtained from a combination of scouring followed by drying. It was, in fact, this latter treatment which provided perfect results with two types of impregnating varnish. (See Tables 40 and 41.)

Improved results may be anticipated therefore, on cloths which have been carefully scoured to free them of size, lubricant, and antiseptic. If they are then dried thoroughly by heating, and immersed immediately in varnish, it will only be necessary for the varnish to be capable of wetting the clean filament surface. This brings the formulation of an impregnating varnish with satisfactory wetting properties within the realm of possibility, and the problem is reduced to that of discovering oleo-resinous or other combinations which wet clean cellulose, cellulose acetate, glass, nylon, etc.

2. The Viscosity of the Impregnating Varnish. Obviously the higher the viscosity of the varnish the more difficult it will be to force it between the twisted filaments. Viscosity of the varnish can be reduced by addition of solvent or by choice of constituents. Incidentally the results given in Table 42 show that white spirit is not the ideal solvent for this purpose, if low interfacial tensions are required.

Viscosity of the varnish can also be reduced by raising its temperature. Vacuum and/or pressure will also assist to force a varnish into its proper place.

3. Construction of the Textile Support. Cotton fibres, unfortunately, are of hollow construction and the microscopical dimensions of their hollow spaces make impregnation difficult, if not impossible. The more effectively cotton is starched the smaller the chance of forcing varnish through the starch barrier into the cloth itself.

All textile threads are twisted to various extents, and the harder the twist the more difficult the penetration of varnish becomes. Natural silk threads have very little twist and are therefore excellent in this respect.

4. Characteristics of the Varnish. It has been explained already that the interfacial tension of the varnish is important for best penetration, and that this can be adjusted by formulation. The

varnish, in addition should have a high non-volatile content, for even having satisfactorily accomplished impregnation initially, subsequent evaporation of volatile matter during drying must leave voids—unless the non-volatile portion remains liquid enough to flow into them.

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CHAPTER IX

METHODS OF ANALYSIS AND TESTING

THE IMPREGNATING VARNISH

FROM the user's point of view there is very little testing of the varnish which needs to be conducted. Many proofers rely solely upon the integrity and experience of the varnish manufacturer, and do not perform any tests whatsoever on the varnishes they receive. In other words, they place the full responsibility of supplying consistently satisfactory varnishes on the varnish manufacturer. The larger and more efficient proofers conduct check tests on every batch of varnish delivered.

If any great error in the manufacture of the varnish occurs it is quickly revealed by very simple physical tests. These include specific gravity, colour, and viscosity. If a proofer is continually ordering the same quality of varnish from one supplier, these physical properties of each batch will fall within fairly close commercial limits.

When these properties on testing fall outside the usual range of the limits, the user is entitled to be suspicious of a fundamental change, either in constituents or in manufacturing procedure.

At the same time as these tests are conducted the varnish is easily examined for skins, bittiness and opalescence. A satisfactory varnish should be free of all extraneous matter and absolutely star-bright. Any varnish exhibiting opalescence or turbidity should be referred back to the varnish manufacturer.

There are, among other properties, four which efficient proofers check continuously; they are drying properties, flexibility, percentage of non-volatile constituents and acidity.

The drying properties of a varnish are readily checked. The varnish is thinned with a suitable thinner, usually white spirit or other petroleum distillate, to a viscosity which, after application by dipping to the textile support, yields a varnished cloth of normal thickness. The impregnated cloth is then suspended in a small experimental oven, and dried at a temperature, and for a time, corresponding with the drying conditions in the proofer's tower. This easy test will serve as a preliminary guide to the drying properties of the varnish, and will enable a more comprehensive test to be carried out with confidence in the tower itself.

This second drying test in the tower, is inconvenient whenever it is done, and the preliminary test, conducted away from production processes is a good safeguard against waste of time and output. If desired the drying test in the tower can be performed on two or three yards of cloth under identical production conditions. Defects of flow, impregnation, film formation and flexibility are thereby exposed.

Percentage of Non-volatile Constituents

When a proofer first meets a new impregnating varnish he is interested to know whether he is really obtaining good value for the money he pays for it. The cheapest constituent of almost every varnish is its solvent or thinner, and the more thinner which can be introduced by the varnish manufacturer, the cheaper the raw material cost of the varnish to him. There is, therefore, some tendency by unscrupulous varnish manufacturers to polymerise varnishes to a very high degree in order to introduce excessive amounts of thinner.

This means more profit to them, but the proofer pays for volatile thinner which disappears out of the ventilators of his tower. As customers have become more enlightened this practice has nearly died out; when it is exploited it is usually with moderation and due consideration of the necessity for retaining other properties. What the proofer is interested in primarily is to know how much non-volatile varnish is left on the cloth. The build of the cloth and its electrical insulating properties depend upon the amount and quality of non-volatile varnish film on it.

The percentage of non-volatile constituents in a varnish can be determined by the following procedure. A clean, flat bottom, porcelain dish of 8-inch diameter, or a tin lid of similar dimensions, together with a 4-inch length of glass rod, is heated in an oven at 120° C. for one hour to remove moisture. It is then allowed to cool in a desiccator, weighed, and about 2 grams of impregnating varnish added. The whole is then re-weighed to ascertain accurately the amount of varnish used. Rapid weighing is essential because thinners are volatile. If very volatile thinners are suspected of being present, it is better to determine the weight of varnish used, by difference, using a weighing bottle. A check determination is carried out concurrently.

The dish is then heated at 120° C. until no further loss in weight is detected. Since most varnishes absorb appreciable amounts of oxygen in drying, it is not always possible to determine the true

non-volatile content, for as the volatile matter is evaporated away, some oxidation occurs. The weight which should be taken is the minimum weight, and the percentage non-volatile matter calculated from it is generally accepted in the trade as being sufficiently accurate for most practical purposes. The original weight of the dish and rod subtracted from the minimum weight of the dish, rod and non-volatile varnish residue, gives the weight of non-volatile matter in the 2 grams or so of varnish taken initially.

Many varnishes tend to skin over when forcibly dried in a hot oven, and the skin, if left intact, prevents the volatile matter from escaping freely. The glass rod is used at intervals to keep the skin broken.

More accurate non-volatile determinations are effected by subjecting the varnish to a distillation process. This may be conducted at ordinary pressure, or under vacuum; sometimes, if only water immiscible thinners are present in the varnish it is advantageous to perform a steam distillation. These methods of distillation can be modified so that the process is done in an inert atmosphere; either nitrogen or carbon dioxide can be passed through the distillation flask, and their presence prevents oxidation of the hot non-volatile varnish residue. Distillation under vacuum is equally effective in preventing oxidation, but the method suffers from the disadvantage that a substantial amount of the distillate is lost by evaporation, unless elaborate precautions are taken. Distillation at ordinary pressure yields all the volatile thinners, and these may be examined further if desired.

Another advantage of distillation methods, over the first method outlined for percentage non-volatile determination, is that the non-volatile residue is also obtained in a satisfactory condition for further examination. Distillation methods are, however, more laborious, in that they require appreciable time to set up the necessary apparatus, and need constant attention when in operation.

Acidity

The acidity of a varnish in the liquid state may be accepted quite often as an indication of its quality. High acidity indicates the use of doubtful constituents like rosin or natural copal; that the processing of the varnish has not been carried to completion in the case of synthetic products; or that the temperatures of the processing have been excessive.

It is believed in many quarters, but by no means confirmed, that

the free organic acids in varnishes attack the threads of textiles and reduce their strength.

The acidity of a varnish is frequently referred to as its acid value, and it is recorded as the milligrams of potassium hydroxide necessary to neutralise the free acidity in 1 gram of varnish.

From 1 to 5 grams of varnish is weighed accurately into a conical flask (250 c.c.). In another flask 50 c.c. of a mixed solvent consisting of equal volumes of ethyl alcohol and benzene, is neutralised with $\frac{N}{10}$ potassium hydroxide solution, using three

drops of 1 per cent. phenolphthalein solution as indicator. The amount of potassium hydroxide necessary to neutralise the free acidity of the mixed solvent is usually only a drop or two, before a permanent pink colour is obtained. The neutralised solvent is then added to the weighed quantity of varnish in the flask and a homogeneous solution is obtained by shaking. If the varnish does not dissolve easily into the solvent, it is permissible to warm it gently, but the contents of the flask should be cooled to room temperature again before proceeding further. The $\frac{N}{10}$ potassium

hydroxide is then run slowly into the solution of varnish, with constant shaking, until a permanent pink colour is obtained. The volume of hydroxide required for this is noted. (x c.c.).

The acid value of the varnish is calculated from the following expression :—

$$\text{A.V.} = \frac{x \text{ (c.c.)} \times 5.61}{\text{wt. of varnish (gm.)}}.$$

The authors prefer to use aqueous potassium hydroxide because it is their experience that a sharper and more easily detected end-point is obtained. Other operators use an alcoholic reagent.

With ordinary clear varnishes there is no difficulty in detecting the precise point at which the contents of the flask become pink, but with black and dark-coloured varnishes this is impossible.

In these circumstances 25 c.c. of a 10 per cent. sodium chloride (A.R.) solution are added to the solvent solution of the black varnish just prior to titration. The potassium hydroxide is then added as before, with continuous shaking, until the bottom aqueous layer becomes pink. It is, of course, necessary to allow the two immiscible layers to settle frequently, during the additions of hydroxide, in order to determine if the aqueous layer has turned pink.

THE TEXTILE SUPPORT

Estimation of Threads per Inch

In order to get an idea of the fineness of weave of a cloth it is necessary to count the number of threads per inch in both directions, *i.e.*, to count the number of ends and picks per inch length of cloth.

There are many different types of cloth counters available and the illustration in Fig. 52 is but one of the simplest.

The instrument consists of a double achromatic lens mounted above and parallel to a frame. The internal dimensions of the frame measure exactly 1 inch along adjacent edges.

It is only necessary to adjust the edge of the frame to coincide with the outside edge of the first thread, and to count away from this edge to the opposite side of the frame. The number of full threads inside the two parallel boundaries of the frame gives the number of threads per inch of cloth. The counting process is repeated in a direction at right angles and so the number of both ends and picks is determined.

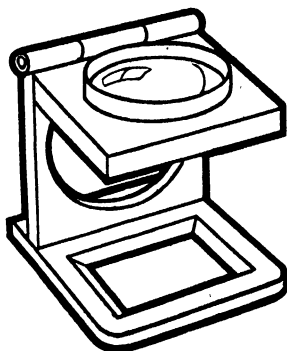


FIG. 52. Cloth counter for estimating threads of cloth per inch.

Estimation of Counts

This is readily estimated by determining the weight of a measured length of thread, removed carefully from the cloth.

One thread weighs $8\frac{1}{2}$ grains per yard, and the number of yards of thread that weigh $8\frac{1}{2}$ grains gives the counts of the thread.

Let ten warp threads each 2 inches long be separated from the cloth and weighed. Let this weight be x grains.

Hence 20 inches warp thread weigh x grains.

Hence length of thread weighing 8.8 grains is $\frac{20 \times 8.8}{86 \times x}$ yards, and this gives the counts of the warp thread.

The Detection and Differentiation of Oxy-, Hydro-, and Pure Cellulose

The detection and differentiation of these two types of cellulose is possible by analytical methods based on solubility differences,

the absorption and colour change of dyes, and the effect of heat.

1. **Solubility in Acetic Anhydride.** Hydrocellulose dissolves in boiling acetic anhydride without any difficulty, but neither pure cellulose nor oxycellulose are soluble.

2. **The Schwalbe and Becker Test.** The cotton under examination is first moistened with distilled water and then treated with methyl orange. If only pure cellulose is present the normal colour of the dyestuff remains unchanged, but oxycellulose converts the bright orange to a brown colour.

Confirmation may be obtained by developing the test further. If a few drops of sodium chloride are added to the spot previously treated with methyl orange the colour changes to a deep red in the presence of oxycellulose. Neither pure cellulose nor hydrocellulose produce any effect.

3. **Effect of Heat.** Hydrocellulose is very sensitive to temperature rises. At 40° C. it becomes yellow, and if the temperature is increased to 100° C. it turns black. Under this treatment oxycellulose remains unchanged unless alkalis are present.

The Determination of Oxycellulose in Cotton

The method described below is based on a determination of the copper number. The results obtained from it must not be regarded as strictly accurate because there are several complicating factors which lead to a certain degree of unreliability. The method is based on the reduction of the cupric copper in the reagent to cuprous copper by the cellulosic material. The copper number is defined as the number of grams of copper which are reduced by 100 grams of cotton. Thus the higher the copper number the greater the amount of oxycellulose present. Copper numbers vary from zero for pure cotton or cellulose to 14 for cotton containing a large amount of oxycellulose.

The test merely consists in boiling a weighed amount of cotton with Fehling's solution.

Fehling's solution is prepared by blending, just prior to use, the two following solutions in equal volumes.

1. Copper sulphate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$), 84.6 g. in 500 c.c. water.

2. Rochelle salt, 178 g., and caustic soda, 64 g., dissolved in 500 c.c. water.

Twists per Inch Test

Usually proofers and others, with the exception of textile manufacturers, do not need to know the number of twists per inch

with great accuracy, and the following very simple test described by Curtis (2) gives a rough but satisfactory estimate.

One end of the thread under examination is fixed between the jaws of a heavy spring paper clip. One inch away from this clip a lighter clip is fixed. The lighter clip is then carefully rotated until it is possible to slide a needle through the thread easily from one clip to the other. The number of revolutions of the clip before this is possible gives the number of twists per inch.

Better accuracy may be obtained if several separate tests are done. If great accuracy is required special twist testers are used.

Determination of Scouring Loss

It is often of importance both for the proofer and the varnish manufacturer, to know just how much size and other constituents are present in the raw cloth which has to be impregnated. As explained already, foreign matter in the threads of the textile support may influence the drying of the impregnating varnish and its penetration.

Two neat squares of cloth (each weighing 5–10 grams) are cut from the piece, care being taken that the cuts are made parallel to the warp and weft threads. Then, in order to avoid the threads near the edges of the specimen from becoming detached during handling, half a dozen or so are carefully separated from the four sides of the specimen to leave a fringe.

Both specimens are weighed accurately and one is extracted for soluble matter, while the other is heated at 110° C. to constant weight to determine the moisture content.

The extraction is conducted by refluxing in a Soxhlet extractor for one hour with chloroform. If desired the soluble material may be determined by evaporating off the chloroform. The cloth is dried in the air and then refluxed for a further hour with distilled water. Finally it is immersed in a warm dilute aqueous solution of diastase ($\frac{1}{2}$ per cent.) for six periods of five minutes each, with a squeezing between the fingers after each immersion. The cloth is finally immersed in diastase solution at 80° C. for thirty minutes, removed and washed thoroughly with boiling distilled water.

The cloth is finally dried to constant weight. The actual amount of chloroform and water soluble material in the cloth, is obtained by calculating the total percentage loss in weight of the cloth, and subtracting from it the percentage loss in weight attributable to its natural water content.

Table 45
Summary of Chemical Identification Tests for Artificial Silks (5)

Variety of Artificial Silk	Behaviour on ignition (6)	Solution of iodine in potassium iodide (6)	Chemically pure sulphuric acid (7)	Diphenylamine pure sulphuric acid (6)	Ammoniacal silver nitrate (6)	Alkaline silver nitrate* Boil solution for 1 min. (8)	Ruthenium Red (9)	Acetone (6)	Chloroform (6)	Very dilute methylene blue solution (10)	Naphthylamine Black 4B. (8)
Viscose	Burns like cotton leaving only a fine white ash	Greenish-blue	Reddish-brown; in 4-1 hour rusty-brown	No colour	Reddish-brown	Dark brownish-black	Bright pink	Insoluble	Insoluble	Light blue	Light reddish grey
		Bluish-green	Yellowish; 4-1 hour yellowish brown	No colour	Unstained	Very light grey	Scarcely coloured	Insoluble	Insoluble	Pale blue	Dark bluish-grey
Cellulose acetate	Burns like natural silk leaving a cinder	Reddish-brown	—	No colour <i>Note.</i> Nitrocellulose gives a deep navy blue	—	—	Slightly and irregularly stained	Soluble	Soluble or forms a gel	Slight coloration	—

* Reagent consists of: 1 per cent. AgNO_3 ; 4 per cent. NaOH ; 4 per cent. sodium thiosulphate.
(By permission of E. Wheeler Esq., and Chapman and Hall Ltd.)

Chemical Identification Tests for Artificial Silks

Table 45 is a summary of the identification tests for the common types of artificial silk.

There are, in addition, other simple tests which may be used in conjunction with them, and they are included below :—

1. **Cellulose Acetate** is soluble in glacial acetic acid.

2. **Cuprammonium Silk** is distinguished from viscose by the action of Pontamine Scarlet B. Samples are heated with the colour at 65° C. for ten minutes. The cuprammonium silk assumes a heavier shade.

3. **Viscose** contains traces of sulphur and confirmation of its presence indicates that the artificial silk under examination is viscose. The silk is heated in a flask in a steam bath for five hours with dilute sulphuric acid (8 c.c. acid in 100 c.c. water). If viscose is present the sulphuretted hydrogen discharged turns a lead acetate paper black. Cuprammonium gives no result.

THE VARNISHED CLOTH**Tackiness Test**

Tackiness is determined by a test described in Specification T.C. 200, 1940, for oil-dressed fabrics. "Two strips of material, each 6" × 3" shall be placed together in an oven maintained at 38° C. $\pm$ 1°, and loaded uniformly over half its area with a 3½ lb. weight placed at one of the ends. At the end of 24 hours the weight shall be removed and the pair of test pieces taken from the oven, carefully and without separating the surfaces, placed on a horizontal surface, and allowed to stand for 10 minutes at room temperature. The appropriate weight shall be hooked to the free end of the lower strip, and the free end of the upper strip raised without jerking at a uniform rate of one inch per second. The surfaces of the material shall separate without lifting the weight. The 3½ lb. weight may be a rectangular block of brass measuring 3" × 3" × 1½", and a weight of 3½ lb. distributed over the area specified above is equivalent to a pressure of 56 lb. per square foot." *

A recordable measure of the tackiness of the surface of varnished cloth can be obtained with reasonable accuracy by attaching an increasing load to the lower strip, until on raising the upper strip the two separate without lifting the load. There is, however, a danger of the force caused by the weight being concentrated over

* Included by kind permission of the Controller of H.M. Stationery Office.

a small distance of the width of the strips, if it is simply hooked on to the bottom strip by means of a hole at the centre. It should, of course, be distributed uniformly over the whole width, and this is best accomplished by hooking the load to a light bulldog clip equivalent in length to the width of the strip. An allowance must be made for the weight of this clip when recording the total weight necessary to cause separation.

The method is not suitable for varnished cloths which are almost tack-free, because the weight of the lower strip alone is often enough to cause separation.

Nevertheless the test can be used to provide information on the tackiness of many different types of varnished cloth, by reducing or increasing the area of the tacky surfaces which are in contact, and by increasing or reducing the load for separation.

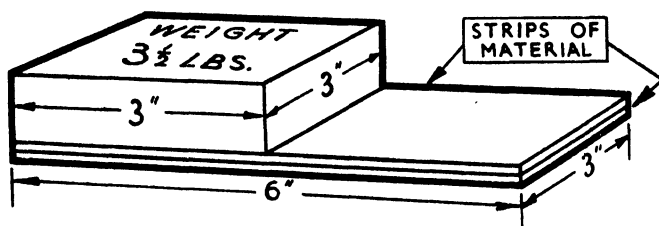


FIG. 53

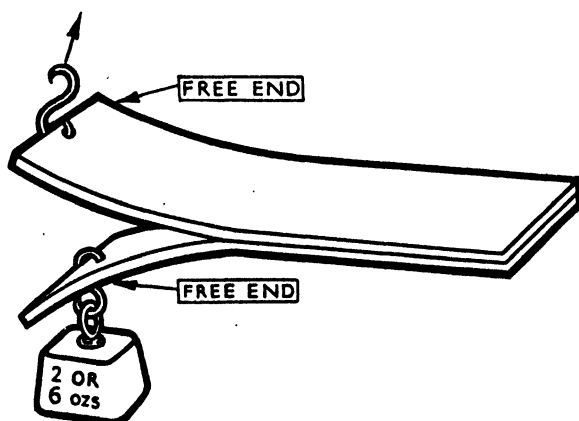


FIG. 54

Method of conducting the Tackiness Test. (Drawing shows the weight hooked to the lower strip. As explained in the text a more even separating load is given by the use of a bulldog clip.)

The temperature at which the surfaces are pressed together by the $8\frac{1}{2}$ lb. weight can be adjusted also from the 38° C. suggested, to suit special conditions. Tackiness is stimulated by increasing the temperature of the test.

It is sometimes necessary to do tackiness tests in duplicate, or to compare the tackiness of several different cloths simultaneously. This can be done by placing all the pairs of strips together under the $8\frac{1}{2}$ lb. weight, but great care should be exercised to avoid adhesion between adjacent pairs. The introduction of rectangular sheets of blotting paper between the separate pairs of strips prevents this.

For varnished cloths which are very sticky on both surfaces it is not advisable to do more than one test at a time, and in any case they cause difficulties by adhering to the blotting paper which is used to isolate them from the flat base of the $8\frac{1}{2}$ lb. weight. The attempted removal of the blotting paper from the back surface of the strips, or from the weight, is liable to disturb the surfaces whose tackiness is under measurement.

For very sticky cloths, therefore, the method is not always convenient, although good results have been obtained by reducing the temperature of 38° C. to air temperature (20° C.), and inter-leaving with waxed paper in place of blotting paper.

The actual method of performing the tackiness test is shown in the illustrations on p. 178.

Determination of Stability on Storage

This test is conducted to estimate how varnished cloths will behave on long storage, and an accelerated ageing test of this type has been developed. It is an attempt to provide, in a few days in a laboratory, an idea of the storage properties, which otherwise might occupy many months, if not years, under natural conditions. The storage conditions in the U.K. are usually kind to varnished cloth, but in humid and hotter climates deterioration is accelerated.

Everything has not yet been said on the precise relationship between the results of accelerated ageing tests and those obtained under natural conditions. Much careful experimental work has still to be done. The test described below does, however, give some indication of the probable storage life under tropical conditions as well as the useful life under temperate conditions; the ninety hours' treatment in the brass box, used in the test, is believed to be equivalent to nine months or a year's storage under

tropical conditions, if the varnished cloth is in roll form. Under conditions where there is free circulation of air, the effective life

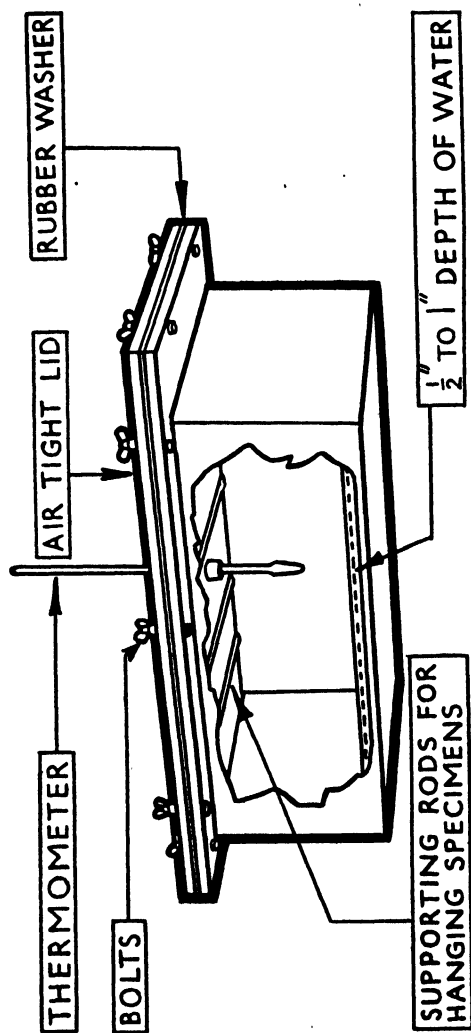


FIG. 55 Brass box and accessories for the stability test.

of the cloth is extended considerably—possibly up to eighteen months or more.

The actual duration of the accelerated ageing test may be

extended from the specified 90 hours to 120 hours or more, and the temperature of the test raised above 70° C., if a longer tropical storage life is required.

The test is conducted in accordance with Appendix III of Specification T.C. 200—1940.

"Strips of material (6" × 3" for tackiness tests and 10" × 4" for tensile strength tests) shall be suspended in a suitable brass box, hanging freely and separately over, but not dipping into a layer of water sufficiently deep ($\frac{1}{2}$ –1 inch) to maintain a relative humidity of 100 per cent. within the box. The box shall be closed by means of a clamped-on lid, provided with a rubber washer to render it air-tight, and be maintained at a temperature of 70° C. $\pm$ 1°. At the end of 90 hours, it shall be opened and the test pieces hung for 24 hours in a drying chamber." * The 6 × 3-inch strips are tested for tackiness according to the test described already, and the 10 × 4-inch strips for tensile strength in the Goodbrand machine.

Deterioration of varnished cloth on ageing is shown by development of tackiness, and loss of tensile strength, and hence both these properties are assessed at the conclusion of an accelerated ageing test.

"A brass box suitable for containing the strips measures 8" × 4" × 8" deep internally and can conveniently hold 12–18 strips. A box suitable for tensile strength test strips measures 12" × 5" × 12" deep and can conveniently hold 18–24 strips. The drying chamber shall consist of a closed cabinet maintained at 20° C. $\pm$ 5°, and containing a tray of anhydrous calcium chloride, the air in the cabinet being kept in constant circulation by means of a fan."

The brass boxes are heated to 70° C. by placing them in a thermostatically controlled oven. Another method of reaching the temperature is by means of an immersion heater placed below the surface of the water in the bottom of the box.

Loss of strength of varnished cotton on storage is also determined from the fluidities of solutions of the regenerated cotton in cuprammonium reagent. The method of doing this is described in a later section.

The illustration on p. 180 gives a general impression of the brass box used for the accelerated ageing tests.

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Acidity of Varnished Cloth

The most popular test for acidity or alkalinity is based on an examination of a water extract of the varnished cloth.

Two grams of the cloth are digested in 25 c.c. of distilled water for one hour at 70°–75° C. The distilled water must be freed of carbon dioxide by a preliminary boiling and show a neutral reaction to the indicator used. The *pH* of the water should not be below 6.6 and a satisfactory supply of such water can be obtained without difficulty in a tin-lined laboratory still.

Ten cubic centimetres of the aqueous extract is transferred to a standard white glass test tube ($6 \times \frac{3}{4}$ inch), and an approximate estimate of the acidity is obtained by adding four drops (0.1 c.c.) of the B.D.H. Universal Indicator, or a similar composite indicator, which covers the whole of the practical *pH* range. The relation between the colour and *pH* value of B.D.H. indicator is given by the makers as follows :—

Colour	<i>pH</i> Value
Red	Up to 3.0
Deeper red	4.0
Orange red	5.0
Orange	5.5
Orange yellow	6.0
Yellow	6.5
Greenish yellow	7.0–7.5
Green	8.0
Bluish green	8.5
Greenish blue	9.0
Blue.	9.5
Violet	10.0
Reddish violet	10.5
Deeper reddish violet	11.0

After this preliminary, a more accurate *pH* determination is made by using specially selected indicators, which are sensitive over small ranges of *pH*, according to the method described above, in conjunction with buffered standard tubes, or a colour chart. The indicators given below cover the whole range of *pH* which is likely to be encountered in practice, and when the individual *pH* ranges of two indicators overlap, it is advisable to do a check determination of *pH* using a second indicator.

Bromophenol blue covers the range of pH	.	3.0 to 4.6
Bromocresol green	„ „ „ „ „	3.6 to 5.2
Bromocresol purple	„ „ „ „ „	5.2 to 6.8
Phenol red	„ „ „ „ „	6.8 to 8.4
Cresol red	„ „ „ „ „	7.2 to 8.8

The less common method for determining the acidity or alkalinity of varnished cloth is to take a weighed amount of cloth, normally about 5 grams, and to extract this under reflux with 50 c.c. of neutral carbon tetrachloride or 50 : 50 alcohol-benzene solvent for two hours. Three drops of phenolphthalein indicator are added to the solvent solution, and when cool it is titrated with

$\frac{N}{10}$ aqueous or alcoholic potassium hydroxide. The number of

cubic centimetres of hydroxide necessary to achieve neutrality again are noted, and the calculation is the same as that given earlier for the determination of the acidity of impregnating varnish. The weight of varnished cloth is substituted for the weight of varnish in the formula.

By this means the acidity of the complete varnished cloth is obtained. If it is desired to obtain an estimate of the acidity of the dried varnish film on the cloth only, then a determination of the percentage of proofing varnish in the varnished cloth must be made separately. An adjustment is then made in the original weight of varnished cloth taken, in order to obtain the actual weight of dried varnish present.

The determination of the percentage of varnish on varnished cloth is described in the next section.

Percentage of Varnish on Varnished Cloth

The determination of the percentage of varnish on a varnished cloth serves two purposes simultaneously. It fulfils its primary object, and also yields a specimen of unproofed fabric for further examination. The proofer is often anxious to know what type of textile support his competitors are using, and this information is readily obtained by removing the dried film of varnish from a specimen of varnished cloth, by a combination of solvent extraction and chemical action.

Such a method is described in detail in Appendix I of Specification T.C. 200—1940. "About 5 grams of the fabric cut into strips if necessary, shall be dried at 98–102° C. for half an hour,

cooled in a desiccator and weighed (W_1). The dried fabric shall be transferred to a Soxhlet apparatus and extracted with methylene dichloride for half an hour. The extracted fabric, together with 50 ml. of approximately semi-normal alcoholic potash, shall then be placed in a flask fitted with a reflux condenser and heated for a further half hour.

"At the end of this period the fabric shall be transferred to a suitable vessel and washed thoroughly with two successive quantities of 50 ml. of hot water, and once with 50 ml. of $\frac{N}{10}$ hydrochloric acid. After washing with a further 25 ml. of hot water, the fabric shall be given a final wash with 25 ml. of alcohol.

"The fabric shall then be dried for half an hour at 98° – 102° C., cooled in a desiccator and weighed. (W_2 .)

"The percentage of proofing, P, shall be calculated from the formula :—

$$P = \frac{100 (W_1 - W_2)}{W_1} \text{ in which}$$

W_1 denotes the weight of dry proofed fabric and

W_2 " " " " " " fabric after removal of the proofing as determined above." *

The "Heating Up" Tendency of Varnished Cloths

The "heating up" of varnished cloths is caused by one or other of two factors ; sometimes both factors combine to accentuate the trouble. The first factor is faulty formulation of the impregnating varnish, and the second is insufficient drying treatment by the proofers.

The method used to assess the "heating up" tendency is a modification of that devised by Mackey, (4) the only alteration being that the cotton wool soaked in oil of the original test is replaced by a series of discs of varnished cloth.

The apparatus consists of a calorimeter surrounded by a water jacket, and the details of construction are shown in the accompanying illustrations on p. 185. Inside the calorimeter is a cylindrical cage, C. Circular discs of the varnished cloth under examination are cut with a sharp cork borer or by some other means, to a size so that they fit snugly into the cage. A hole is bored through the centre of the pile of discs to accommodate a

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thermometer. For comparison purposes a standard weighed amount of varnished discs is placed in the cage.

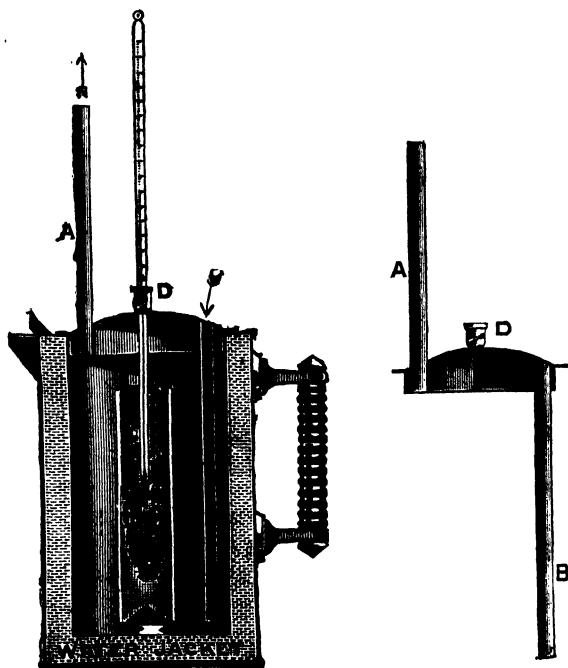


FIG. 56. Mackey's apparatus, which can be used to measure the "heating up" tendency of varnished cloths.

The water is gently boiled in the outer jacket and when this is taking place smoothly, the loaded cage is introduced with the thermometer, and the lid is slipped over the thermometer and into position.

The water is kept boiling for one hour and the reading of the thermometer noted. Any temperature above 100°C . indicates that heat is being generated by the pile of varnished cloth, and the higher the temperature recorded the greater the tendency for the particular sample of varnished cloth to ignite spontaneously.

If the duration of the test is prolonged more than one hour the temperature may increase further.

The progress of the test should be watched very closely for any sudden temperature rise, for defective varnished cloths may char

and burst into flame under these conditions and the thermometer may be damaged.

Assessment of the Degradation of Cotton Cloth and Rayon, Raw and Varnished, Based on Fluidity Measurements in Cuprammonium Reagent

The fluidity of a solution is calculated from the following equation :—

$$Fd = \frac{C}{t - \frac{K}{t}} \quad \text{where}$$

F is the fluidity ;

d is the density of the solution under examination ;

C is the viscometer constant ;

t is the time of efflux of a given volume of solution in secs. ;

K is the kinetic energy correction constant.

Fluidity measurements are not a true indication of all forms of cellulose degradation. Broadly, any degradation arising from chemical reaction is exposed by an increase in fluidity. Such purely chemical degradation includes the loss of strength of cloth due to the chemical action of applied impregnating varnishes, both initially, after stoving, and on ageing ; and the loss of strength of raw cloths containing mineral salts which have been exposed to high temperatures during storage, or cloths which have been subjected to bleaching or other chemical processes. It has been found that whenever chemical treatment increases fluidity, mechanical strength diminishes simultaneously. Hence fluidity measurement can be used as a fairly safe means of determining any loss of strength which is the direct result of chemical interaction.

But fluidity measurements are not a true measure of all forms of mechanical strength loss. High-pressure calendering, a process to which the calendered cotton cloth of varnished cloth is subjected, can easily disintegrate fibres, if the process is not carefully supervised, and the resultant cloth will be mechanically weak. Loss of strength arising from the attacks of mildew on storage are not satisfactorily revealed by fluidity determinations.

To understand how fluidities are a measure of chemical degradation of cellulose it is best to examine the probable effect on the individual molecules. Cellulose molecules are believed to consist of exceptionally long chains in their natural state. These, when dispersed in suitable solvents, give very viscous solutions—in

other words their fluidities are low. It seems likely that chemical attack degrades the long chains into smaller molecules with shorter chains, which when dissolved, give higher fluidities.

Fluidity measurements in cuprammonium reagent can be conducted with advantage, therefore on :—

1. The unimpregnated cotton or rayon support to ascertain if it has deteriorated during storage.

2. The unimpregnated cotton or rayon support to ascertain if it contains injurious chemicals. Such chemicals are acids from various types of salts such as magnesium sulphate and chloride, and zinc chloride. If cotton containing any of these impurities is heated at 110°C . for twenty-four hours it is tendered and its fluidity is increased.

3. The varnished cloth, to ascertain if the constituents of the varnish or the oxidation products set free during the drying process, have any disintegrating effect.

4. The varnished cloth after normal or accelerated ageing, to ascertain the tendering effect of varnish degradation products over long periods of time.

With the last two measurements it is necessary to remove the varnish from the cloths before attempting their solution in the cuprammonium reagent. This is accomplished by the means described already under the method for the determination of varnish on varnished cloth. Boiling with ordinary dilute caustic soda, often suffices to remove all the varnish from the cloth, but whatever means is adopted for varnish removal care must be taken to wash the cloth free of alkali or neutralising acid. The cloth is gently but effectively dried before an attempt is made to effect a solution. In drying the cloth it is obvious that a long exposure to high temperature should be avoided, for this condition in itself is likely to cause severe tendering. Washing with alcohol to remove the last traces of water, followed by careful drying at 50°C . for an hour or so, is usually satisfactory.

Pure cellulose gives solutions with very high viscosities in the cuprammonium reagent, and thus low concentrations are used. A convenient concentration for a cotton solution is 0.5 per cent., and for rayon 2 per cent. In both instances fluidities are recorded in c.g.s. units. A special type of capillary viscometer designed by Clibbens and Geake is suitable for the fluidity determination. (1)

Using a 0.5 per cent. cellulose solution in a standard cuprammonium reagent, fluidities range from about 2 for pure cotton cellulose to approximately 70 for the pure reagent.

The cuprammonium reagent is sometimes known as Schweitzer's reagent, and this consists of copper—15 grams, ammonia 240 grams and nitrous acid 0.5 grams, dissolved in water to give one litre.

The standard cuprammonium reagent used by the British Cotton Industry Research Association, (5) based on Schweitzer's reagent, is :—

15 ± 0.1 grams of copper per litre.

200 ± 5 grams of ammonia per litre.

and less than 0.5 grams of nitrous acid per litre.

An estimate of the amount of oxycellulose in cotton is given by the copper number. This is determined by a method described in the section devoted to the testing of textile supports.

Determination of Dielectric Strength

This property, determined under some special condition or other, is possibly regarded as the most important property of varnished cloths, for electrical purposes.

There is considerable laxity in reporting dielectric strengths, and it is as well to reiterate briefly the important factors which influence its magnitude. They are as follows, but they are not necessarily placed in order of importance.

1. Type of applied electric stress—A.C. or D.C., frequency, wave form.
2. Composition of electrode—brass, copper, etc.
3. Size of electrodes.
4. Shape of electrodes.
5. Smoothness and cleanliness of electrodes.
6. Temperature.
7. Humidity.
8. Overall thickness of varnished cloth or film.
9. Nature of textile or other support—cotton, natural or artificial silk, glass silk, tissue paper, etc., or unsupported film.
10. Relation between thickness of support and overall thickness.
11. Rate of increase of electric stress—instantaneous; ten seconds, step by step, etc.
12. Duration of application of electric stress—instantaneous, minute values, etc.

The matter of recording dielectric strengths has to be viewed from two quite distinct angles. The proofer or manufacturer of the varnished cloth is interested in the intrinsic dielectric strength

of the insulating varnish film. Unfortunately he is given, only too often by varnish manufacturers, dielectric strength figures of varnishes which have been obtained under a wide variety of conditions. A lot depends upon the textile support to which the varnish will be applied, but if the proofer knows the dielectric strength of an unsupported varnish film he is aware, at least, of the possibilities of a particular varnish. In practice, however, dielectric strength determinations of naked varnish films present difficulties which have been outlined briefly already. Some metals such as brass or copper inhibit the natural drying properties of varnishes, and this causes abnormally low results, while the task of producing a free varnish film, by peeling it from an amalgamated surface is both delicate and tedious. An alternative is to prepare the film on a steel or stainless steel disc, made to fit snugly on to, and fit in with the contours of the lower electrode. If a series of punctures is made, and this is essential for an accurate estimation of dielectric strength, then a corresponding number of discs have to be prepared and coated.

The nearest approach to a naked or free varnish film is one applied on gampi tissue paper, the paper being less than 1 mil thick. The paper is so light, fluffy and absorbent, that when impregnated it consists almost entirely of varnish; the tiny paper fibres are thoroughly saturated and completely immersed in varnish. It is much more convenient to prepare films of varnish on tissue paper than on a number of metal discs, and in one operation a piece of paper large enough for several dielectric strength measurements can be prepared. There is another advantage too, in using films of varnish on paper, in that the film is dried in a manner similar to that of the varnish on cloth, *i.e.*, it is oxydised from both external surfaces inwards. The drying is therefore likely to be much more thorough throughout the entire thickness of the film, than in the case of a film on an amalgamated surface or on metal, for in these instances it oxydises from one surface only. The value of applications of insulating varnishes on tissue paper has been recognised in some quarters, for the use of tissue paper is stipulated in certain authoritative specifications.

The proofer, too, is only really interested in dielectric strength figures which have been obtained on films stoved under conditions corresponding with the stoving times and temperatures which prevail in his tower. The advantageous effect of stoving varnishes for long times at high temperatures has been emphasised already. It is possible to enhance dielectric strengths considerably by this

treatment, and a false impression can be easily given of the magnitude of dielectric strength attainable under practical conditions.

The authors feel that the time is ripe for the standardisation of test conditions for dielectric strength determinations of impregnating varnishes for varnished cloths. Whilst this preferable state is the process of development, it is suggested that dielectric strength figures are described as having been determined on steel discs or on Gampi tissue paper, after stoving the varnish film for a certain time and temperature. But even the enforcement of these conditions is insufficient for a reliable picture of the dielectric strength figure, for other factors included in the twelve enumerated above must be described in addition. A photograph of the standard B.S.I. brass electrodes appears on p. 104.

The user of varnished cloth, in contrast to the proofer, is not concerned with the dielectric properties of the varnish itself. His main concern is whether the finished varnished cloth, as he receives it, has a satisfactory dielectric strength.

For dielectric strength figures of varnished cloth to be of real value to him he must know the frequency of the electric stress used, the rate of its application and its duration, the dimensions and composition of the electrodes, the temperature and humidity at the time of the determination, and the thickness of the cloth under review. All this information must be available if the user of varnished cloth is to abstract anything of value from the figures he receives from different proofers, which have been determined in all probability, under a variety of conditions. Dielectric strength figures determined simultaneously by one operator under identical conditions are strictly comparable, and it is not always necessary to record full details of the conditions of measurement. It is, however, futile to compare such figures with others obtained elsewhere under unrecorded conditions.

At least six individual dielectric strength determinations should be taken on a given specimen, in order to arrive at a fair average figure. Some operators prefer to do ten or a dozen. A single determination may be very misleading—the overall breakdown voltage can vary as much as 20 per cent. or more, for different parts of a particular specimen. Some of these variations may be attributed to imperfections in the varnish film—particles of grit, fibre or other extraneous matter; or they may be caused by irregular thickness. Many individual measurements of dielectric strength must be made, therefore, for a true average figure, and

similarly a corresponding number of measurements must be made to ascertain the average thickness of the specimen.

Some operators prefer to deduce the average thickness of varnished cloth by measuring the thickness of several layers and dividing the result by the number of layers. Others measure the actual thickness of the cloth precisely at the place of puncture with the aid of a micrometer screw gauge.

Dielectric strength testing equipment must include means of conducting determinations at any temperature, from air temperature up to 150°C . or higher. With the advent of varnished glass silks to function at temperatures of 150° – 200°C ., it is obvious that the ideal equipment must be adjusted to accommodate them also. The electrodes should be housed in a thermostatically controlled, glass-fronted, cabinet, and provision should be made of bars from which to suspend specimens of cloth, so that they may attain the agreed temperature remote from the electrodes. A pocket in the upper electrode should be included for the insertion of a thermometer to ensure that the electrodes themselves are at the desired temperature. As the electrodes are of massive construction, made from metal such as brass, with good thermal conductivity, any divergencies from the desired temperature of a specimen will be rapidly nullified by heat transmitted from the electrodes to a piece of varnished cloth placed between them. Thermostatic control is only of real value when it is certain that the whole of the heated cabinet is at a uniform temperature. If the cabinet is electrically heated the heating elements should be arranged to give a uniform heat distribution, and not merely inserted at the bottom. A small fan or stirrer is a very useful adjunct to attain perfect heat distribution.

The testing equipment must also include a humidity cabinet in which specimens may be conditioned at any humidity from zero to complete saturation. This is fairly easily accomplished by the use of trays containing various selected chemicals, according to the humidity required, and by keeping the air in gentle but constant circulation. If the testing equipment is to have maximum flexibility the humidity cabinet should be capable also of thermostatic control.

It is not improbable that high altitude flying at extremely low temperatures will necessitate dielectric strength determinations under conditions of refrigeration. Embrittlement of the varnish through excessive cold might cause fractures in the film, and electrical breakdown. This is a possibility of the near future and

will make the necessary testing equipment even more complicated.

Two or three voltmeters are necessary to accommodate accurately all the overall breakdown voltages which are likely to be met in practice. If only one voltmeter is used it is impossible to read the lower voltages accurately, *e.g.*, with a voltmeter graduated up to 25,000 volts it is impossible to take readings below 5,000 volts, and with a voltmeter graduated up to 5,000 volts it is usually impossible to read anything below 1,000 volts. Two voltmeters are therefore essential to cover the range 1,000–25,000 volts, and of course, most varnished cloth or varnished tissue paper tests come conveniently within this range. On occasions, however, accurate measurements of voltages are required just above or below 1,000 volts, *e.g.*, on once-run thin fabrics, or on the unimpregnated textile supports; and further, it is sometimes necessary to maintain relatively low voltages on varnished cloths for periods of time. In such cases a third voltmeter graduated for low voltages is essential.

There is very little to note about the actual operational details for dielectric strength determinations. The smooth flat surfaces of the standard electrodes should be cleaned at frequent intervals to remove any adhering material. The piece of varnished cloth should be large enough to permit puncturing without arcing round its edges, and to permit several tests to be made without the risk of arcing through recently formed punctures.

The specimen of varnished cloth is inserted smoothly between the electrodes and the electric stress gradually increased up to the point of breakdown. The precise point of breakdown is normally easily determined by watching the movement of the voltmeter needle as the stress is increased. As soon as the needle ceases to move forward and falls back to zero, a mental note is made of the maximum voltage recorded. With some varnished cloths, however, and with many unimpregnated textiles, the exact end-point is not easy to determine. The electric stress continues to increase, but the voltmeter needle does not record this and remains stationary, and an intermittent spitting and shorting takes place at the electrodes. In such cases the point of breakdown is taken when the intermittent spitting occurs, and when the voltmeter fails to advance in step with the increasing stress.

Because of the high voltages used, all dielectric strength-testing equipment must be adequately insulated electrically and isolated geographically.

“Handleability” of Varnished Cloths

The flexibility and adhesion tests already described in Chapter VII are not a measure of the handling or draping qualities of varnished cloths, although in the performance of these tests indirect indications are given of “handleability.” Flexibility and adhesion tests are designed to measure the resistance of a varnished film to disruption caused by bending, folding or flexing.

Varnished cloths which do not “handle” well, cannot be used conveniently for many of their applications, and a method of determining this property is necessary.

Much, of course, can be conveyed by running the cloth or silk gently and slowly through the fingers, and although more scientific tests have been devised, there are many who prefer this personal test with all its defects, to those with more scientific foundations. This preference may be because, on occasions, cloths which “handle” well do not appear so good according to accurate measurements with certain instruments. Pierce (3) of the British Cotton Industry Research Association has developed a means of accurate measurement of stiffness or hardness of cloths by means of the flexometer.

These measurements are based on the fact that when cloth is pushed over the edge of a horizontal surface the protruding length inclines itself at a definite angle from the horizontal. The smaller the angle of inclination from the horizontal the stiffer or more rigid the cloth. A rough idea of this property may be obtained, therefore, by simply sliding a cloth over an edge and noting, visually, the inclination. Pierce’s instrument, the flexometer, is designed to measure this drooping or inclination accurately.

The illustration (Fig. 57) shows the flexometer. A is a platform hinged at O, and on its upper surface is a scale S graduated in centimetres. Underneath the surface of the platform, remote from the hinged end, is fitted a friction piece, G, which contacts the inner surface of a thick metal circular arc C, and controls the movement of the platform. The circular arc is graduated in degrees, from 0 at the horizontal to 60 below it. Mounted on the same axis as that of the adjustable platform is a pointer B.

Accurate specimens of varnished cloth, measuring 6×1 inch are cut with a razor and template, care being taken to ensure that the actual cuts coincide with the lengthwise threads of the material. The cut specimen is then placed on the plane D, and the end of the length protruding coincides with a graduation mark of the

scale on the platform. The specimen of cloth is secured in place by the weight F, and the platform is then depressed until the specimen hangs separated from it. The pointer B is then adjusted until it just coincides with the end of the specimen, and the angle of depression is then read off from the circular arc.

It is sometimes difficult to decide upon the exact adjustment of the pointer. If the end of the specimen is curved the middle point of the bottom edge is taken. If the specimen of cloth curls slightly when cut, a second reading is taken after replacing the specimen in the instrument with the reverse side uppermost. The mean angle is calculated.

When cloth is examined by this method it is essential that a specimen is chosen which is quite free of folds or crease marks.

The length of specimen overhanging is arranged to give a deflection within the range 20°–30°. "Handleability" is recorded as the bending length (c). It is affected by two factors—the natural resistance of the specimen to bending, and its weight. The bending length is, by definition, the length of fabric which bends to a definite extent under the influence of its own weight. The higher the bending length the stiffer the cloth.

When the specimen under examination is in the form of a rectangular cantilever, and this is the usual form, the expression for calculating the bending length is:—

$$c = l \left(\frac{\cos 0.5 \theta}{8 \tan \theta} \right)^{\frac{1}{3}}$$

where c is the bending length in centimetres ;

l is the length of specimen overhanging in cms.,

and θ is the angle of depression.

The above worker has evolved a series of expressions for calculating the bending length of specimens of various shapes. Specimens are cut to shapes other than rectangular to avoid curling, and to enable exceptionally stiff or flimsy cloths to be examined.

Temperature and humidity make important differences to the results, and it is advisable, for accurate measurement, to condition the specimen and perform the actual bending operation under these controlled conditions.

Determination of Tensile and Tearing Strengths on Raw and Varnished Cloths

In the determination of tensile and tearing strengths it is necessary to use a machine which provides a direct load normal to,

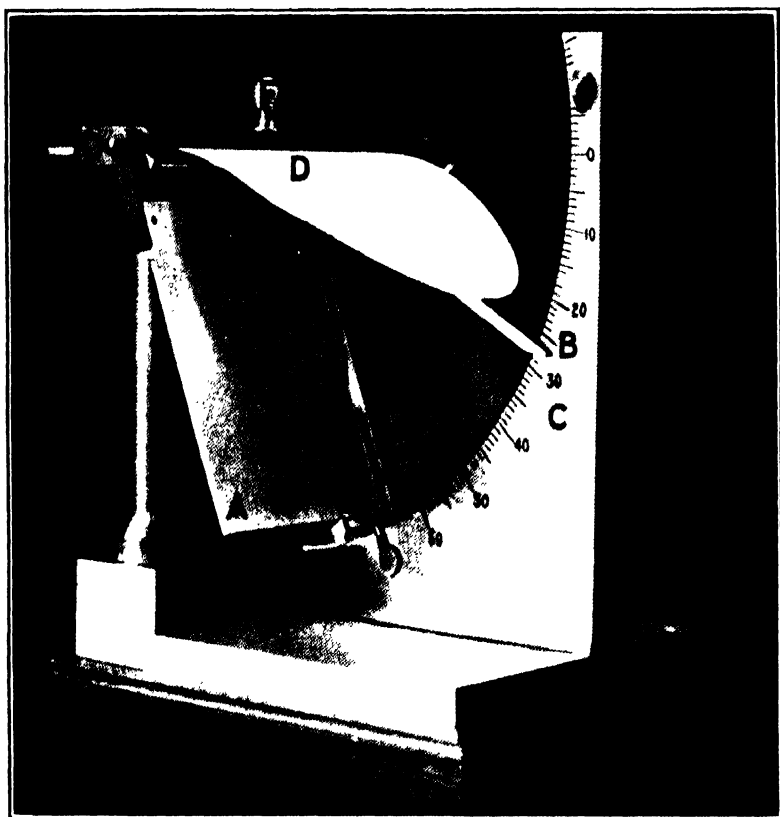


FIG. 57. The Flexometer. For determining the "handle" of varnished and other cloths. A wide specimen of cloth is shown in position. (By kind permission of the Director, British Cotton Industry Research Association.)

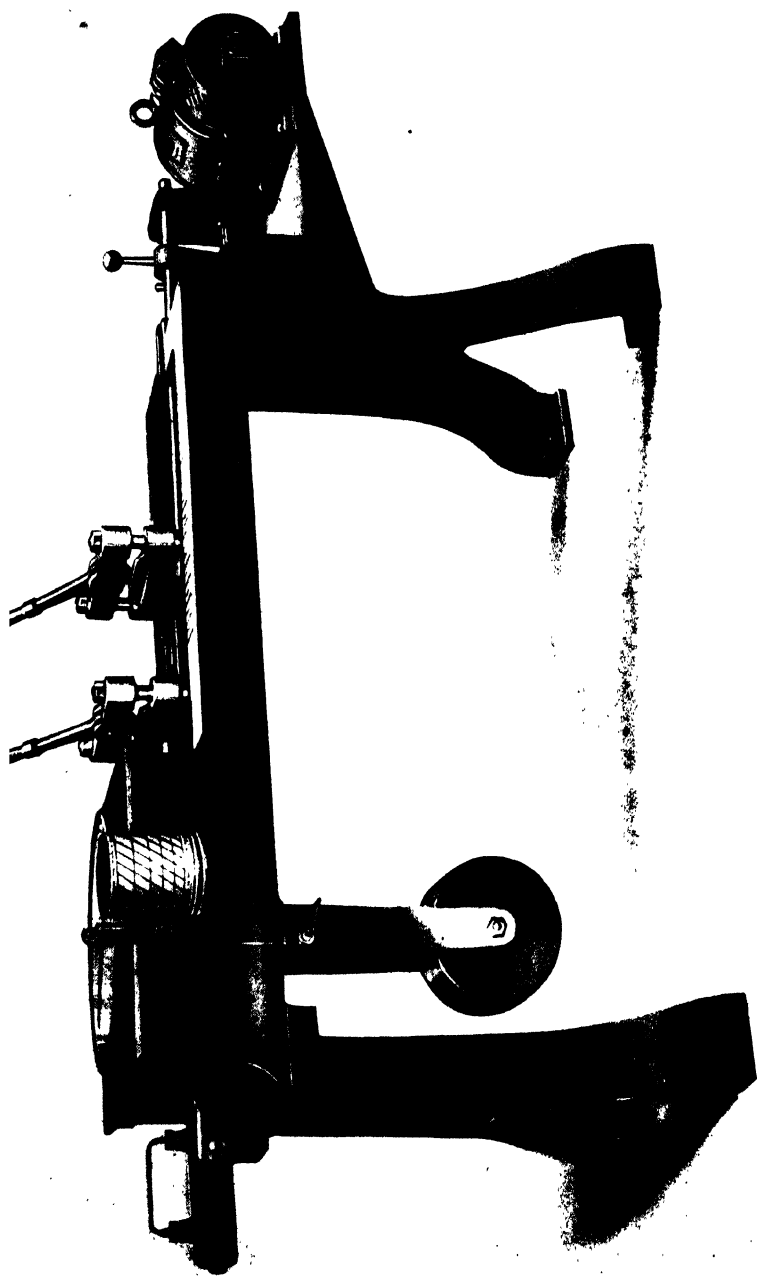


FIG. 58. Horizontal tensile testing machine for cloth (Type C). (By courtesy of Messrs. Goodbrand & Co. Ltd.,
Stalybridge.)

or at right angles to, the warp or weft threads, depending upon the particular tensile strength which it is desired to determine. With bias cut cloth the load must be parallel to the edges of the specimen under test.

The machine used must apply the load at a uniform rate up to the breaking point. There are various types of machine suitable for tensile strength tests and the illustrations (Figs. 58, 59 and 60), show three types. Fig. 58 is for very strong specimens, and is a horizontal machine. Figs. 59 and 60, accommodate other specimens which require lighter loading, and are vertical machines.

It is important in tensile strength determinations that the load is increased at a regular rate—sudden applications of loads give unreliable results. All the machines illustrated are electrically driven, and the grip holding one end of the specimen is withdrawn mechanically at a uniform speed until fracture occurs. It is often useful to have a two- or three-speed gear-box included with the machine so that different rates of traverse can be used for experimental purposes. Sometimes a very slow break is invaluable, because the actual breaking process can be viewed as it occurs.

A popular rate of load application is that it is increased uniformly, so that breakdown occurs in about one minute from the commencement.

Another valuable addition to tensile and tearing strength machines is a stress-strain diagram attachment, and this is shown on each of the machines illustrated. By means of these attachments a permanent record is obtained of the amount of elongation for a given load.

Tearing strength tests on varnished cloths and other textiles are conducted at a standard rate of 12 inches per minute.

The specimens for tensile and tearing strength tests must be cut carefully from the piece; the cuts should exactly correspond with warp or weft threads except in the case of bias-cut cloth. Ten or more specimens are cut from the cloth in both directions in order to get a reliable average, and the location is selected, so that the whole of the cloth is explored. Different specimens must not contain the same warp or weft threads. For tensile strength tests it is obvious that the specimens should be the same width, for the effect of the load on a unit width of the specimen depends upon this. If possible the width of the specimen should include the same number of threads. This is nearly always the case with specimens of identical width if they are regularly woven. If the

break occurs in an irregular manner or in or near the jaws, the result should be ignored.

The methods of determining both tensile and tearing strengths are described in B.S.S. 419—1931, which is included in the Appendix.

It is important that the tests are carried out under controlled conditions of temperature and humidity, for both influences affect the ultimate result. It is not, however, always convenient to arrange for conditions of constant humidity during the performance of the test, and a reasonable compromise is to condition the specimens beforehand in a small cabinet, maintained at constant humidity, and to apply the test within a minute or so of the specimen being removed from these conditions.

The spring balance attachment, as suggested in Appendix VI of the above specification for the determination of tearing strengths requires a fair amount of skill on the part of the operator, and better results are obtained by the use of specially-drawn charts which are designed to show low, mean and high peaks of tear.

Neither of the two illustrations (Figs. 59 and 60) show a tearing strength test in operation, but the procedure is substantially the same as for tensile strength tests, except that suitable grips are substituted.

Other Electrical Tests

Further details of electrical and other tests are given in the standard British and American Specifications which are included in the Appendix.

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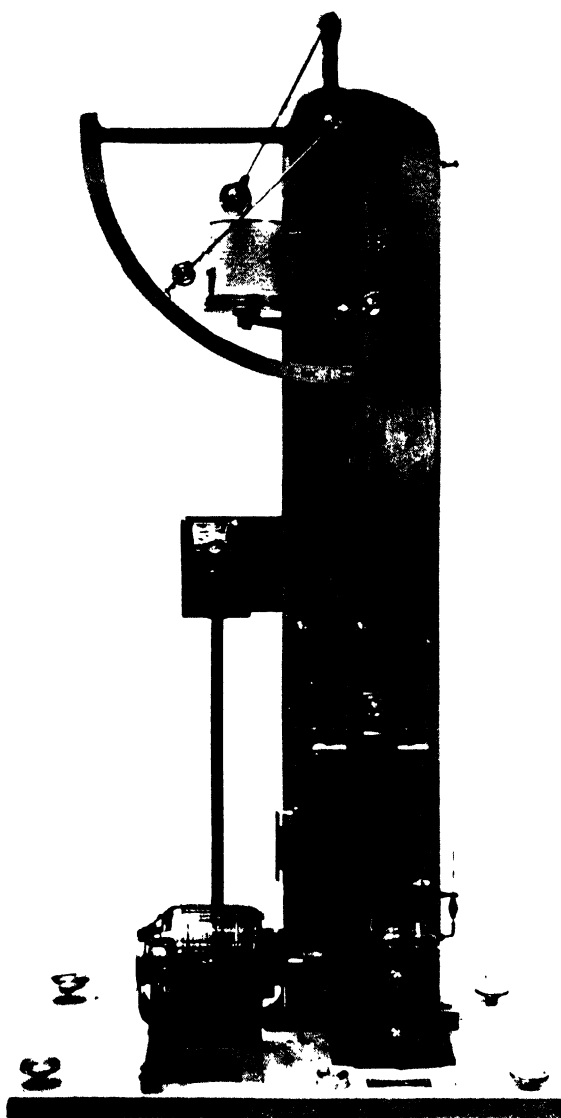


FIG. 59. Light loading tensile or tear strength testing machine for cloth or tape. (By courtesy of Messrs. Goodbrand & Co. Ltd., Stalybridge.)

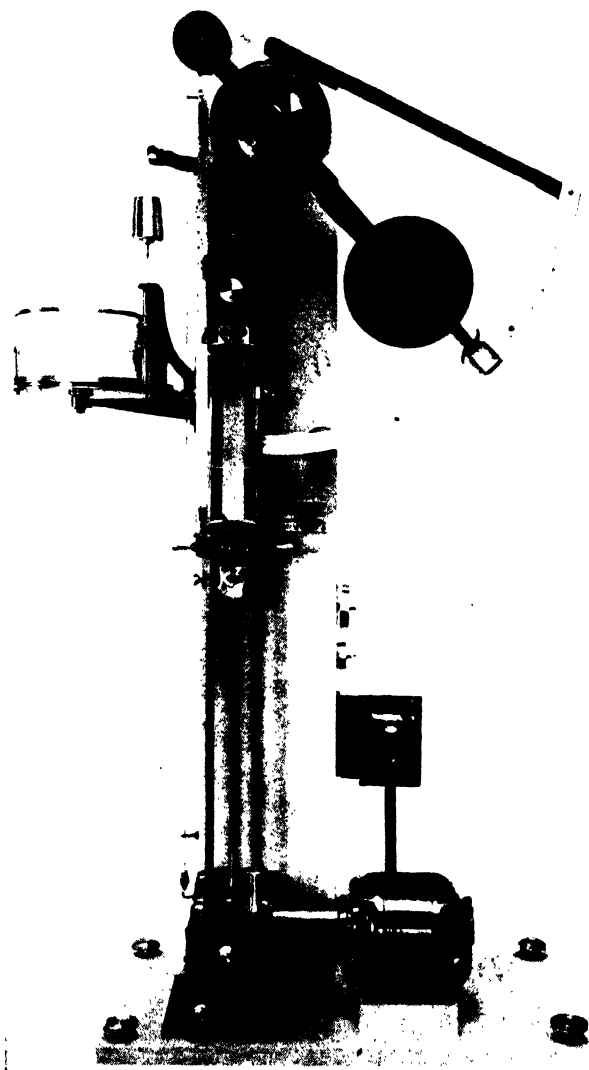


FIG. 60. Heavier loading tensile or tear strength testing machine for cloth or tape. (By courtesy of Messrs. Goodbrand & Co. Ltd., Stalybridge.)

[To face p. 197.

APPENDIX

**BRITISH
STANDARD SPECIFICATION
FOR
VARNISHED CLOTH SHEET, STRIP OR TAPE
FOR
ELECTRICAL PURPOSES
(Excluding Cables)
No. 419—1931.***

Thickness

8. This Specification refers to varnished cloth of nominal thickness of 5 mils (0·127 mm.), 7 mils (0·178 mm.) and 10 mils (0·254 mm.) respectively.

The tolerance on thickness shall not exceed the appropriate value given in Table I. The thickness shall be determined as described in Appendix II.

**Table I
Tolerance on Thickness**

Nominal Thickness		Tolerance
mils.	mm.	per cent.
5	0·127	— 0 + 20
7	0·178	— 10 + 10
10	0·254	— 10 + 10

Width

4. The following tolerances shall be allowed on the widths of materials :—

(a) Sheet. The tolerance on the width of cloth nominally

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36 inches (91.4 cm.) wide, shall not exceed plus or minus 1 inch (25.4 mm.). The tolerance on cloths of widths other than 36 inches (91.4 cm.) shall be the subject of agreement between the purchaser and supplier.

(b) Strip or Tape. The tolerance on width of straight-cut or bias-cut strip or tape up to 6 inches (15.2 cm.) wide shall not exceed plus or minus $\frac{1}{8}$ inch (0.397 mm.).

Joins

5. (a) Straight Cut. Straight-cut strip or tape in any of the lengths specified in Clause 6 (b) shall be free from joins.

(b) Bias Cut. Joins, if any, in bias-cut strip or tape shall be strong. The tensile strength of the sewn join shall be such that the join will withstand not less than twice the appropriate load applied in the test for electric strength under mechanical tension (Tables III, IV, IX or (X)).

The length of strip or tape between any two joins shall be not less than 48 inches (122 cm.).

Rolling

6. (a) Sheet. Cloth shall be rolled on a cardboard or other suitable tube, the width of which shall be not less than the full width of the sheet.

(b) Strip or Tape. Strip or tape shall be wound on a cardboard or other suitable tube, the width of which shall not exceed the width of the tape or strip wound thereon.

The total length of strip or tape in each reel shall be 36, 50 or 72 yards or more, plus or minus 1 yard (33, 46 or 66 metres or more, plus or minus 0.9 metre), as specified by the purchaser.

Packing

7. Sheet, strip or tape shall be packed so as to be well protected from dust, dirt and moisture.

II

REQUIREMENTS FOR YELLOW VARNISHED CLOTH

Electric Strength (Proof Test)

8. Note. The observed electric strength of varnished cloth is much lower when subjected to continuous application of the stress than when subjected to stresses of brief duration such as one minute or less. It is also lower at high temperatures than when cold.

It should be noted that the value of the electric strength resulting from test (a) below does not give sufficient indication of the electric stress which the material can withstand when subjected to service conditions, such indication being given by a test in accordance with Clause 9.

While the electric strength proof test for brief periods (Clauses 8 (a) and (b)) is useful for the purposes of quick check tests, the electric strength under prolonged stress while hot (Clause 9) is the value of chief importance to the designer of machinery and apparatus employing this type of insulation.

The electric strength specified in (b) below checks the ability of material to withstand mechanical tension without damage to the varnish film.

(a) **Electric Strength in Free State at 90° C.** The varnished cloth shall withstand for one minute without failure the voltage computed from the appropriate value in volts per mil specified in Table II, when tested as described in Appendix III.

Table II
Electric Strength at 90° C.
(One minute Proof Stress)

Nominal Thickness		Volts per mil		Kilovolts per mm.	
mils	mm.	Large Electrodes *	Small Electrodes †	Large Electrodes *	Small Electrodes †
5	0.127	450	550	17.72	21.65
7	0.178	500	650	19.69	25.59
10	0.254	550	700	21.65	27.56

The material shall be deemed to comply with the requirements of this clause if it passes not less than four tests out of five.

(b) **Electric Strength of Bias-cut Strip or Tape not less than $\frac{3}{4}$ inch wide, under Mechanical Tension at 20° C.** The electric strength test under mechanical tension shall be carried out on bias-cut strip or tape only.

The strip or tape shall withstand for one minute without failure the voltage computed from the appropriate value in volts per mil specified in Table III, when subjected to the appropriate mechanical tension given in Table III and tested as described in Appendix III.

* See Appendix III (a).

† See Appendix III (b).

When it is necessary to test strip or tape wider than 8 inches (76.2 mm.) the width shall be reduced so that the specimen can be tested in the apparatus described in Appendix III (b).

Table III

Electric Strength of Bias-cut Strip or Tape under Mechanical Tension at 20° C.

(One Minute Proof Stress)

Nominal Thickness		Load		Volts per mil Small Electrodes	kV per mm. Small Electrodes
mils	mm.	Pounds per inch width	Kilogrammes per centimetre width		
5	0.127	3	0.54	700	27.56
7	0.178	4	0.72	750	29.53
10	0.254	5	0.89	800	31.50

The material shall be deemed to comply with the requirements of this clause if it passes not less than four tests out of five.

(c) **Electric Strength of Bias-cut Strip or Tape less than $\frac{3}{4}$ inch wide under Mechanical Tension at 20° C.** The electric-strength test under mechanical tension shall be carried out on bias-cut strip or tape only.

The strip or tape, of which the width is less than $\frac{3}{4}$ inch, shall withstand for one minute without failure the voltage computed from the appropriate value in volts per mil specified in Table IV, when subjected to, and wound on a rod under the appropriate mechanical tension in Table IV and tested as described in Appendix III.

Table IV

Electric Strength of Bias-cut Strip or Tape less than $\frac{3}{4}$ inch wide, under Mechanical Tension at 20° C.

(One Minute Proof Stress)

Nominal Thickness		Load		Volts per mil	kV per mm.
mils	mm.	Pounds per inch width	Kilogrammes per centimetre width		
5	0.127	4	0.72	550	21.66
7	0.178	5	0.89	550	21.66
10	0.254	6	1.08	550	21.66

The strip or tape shall be deemed to comply with the requirements of this clause if it passes not less than four tests out of five.

Maintained Electric Stress (Proof Test) *

9. Varnished cloth of any thickness shall withstand for two hours without failure the appropriate voltage computed on the basis of 60 volts per mil (2.36 kV per mm.) when tested as described in Appendix IV.

The material shall be deemed to comply with the requirements of this clause if it passes two tests out of three.

Tensile Strength

10. The tensile strength of varnished cloth in the warp and weft directions respectively shall be as nearly equal as practicable. The tensile strengths in the several directions shall be not less than the appropriate value given in Table V, when determined as described in Appendix V.

Table V
Tensile Strength

Minimum Tensile Strength

Nominal Thickness		Straight Cut				Bias Cut	
		Warp		Weft			
mils	mm.	lb. per in. width.	kg. per cm. width.	lb. per in. width.	kg. per cm. width.	lb. per in. width.	kg. per cm. width.
5	0.127	25	4.46	15	2.68	15	2.68
7	0.178	30	5.36	20	3.57	20	3.57
10	0.254	35	6.25	25	4.46	25	4.46

The material shall be deemed to comply with the requirements of this clause if it passes not less than four tests out of five.

Tearing Strength *

11. The tearing strength of varnished cloth shall be not less than the appropriate value given in Table VI, when determined as described in Appendix VI.

* Pending the development of suitable methods of tests for this characteristic on strip or tape, this test shall be made on larger sheet specimens from the varnished cloth from which the strip or tape is cut.

Table VI
Tearing Strength

Nominal Thickness		Tearing Strength (Double Tear)			
		Warp Tear (i.e., Travel of Tongue parallel to Selvage across Weft Threads)		Weft Tear (i.e., Travel of Tongue Parallel to Weft Threads)	
mils	mm.	ounces	grammes	ounces	grammes
5	0.127	14	397	18	510
7	0.178	14	397	18	510
10	0.254	16	454	20	567

The material shall be deemed to comply with the requirements of this clause if it passes not less than four tests out of five.

Ageing *

12. The mean decrease in the bursting strength of varnished cloth, due to heat treatment, shall not exceed 60 per cent., computed on the original mean value, when determined as described in Appendix VII.

The bursting strength after ageing shall be not less than the appropriate value given in Table VII.

Table VII
Bursting Strength after Ageing

Nominal Thickness		Bursting Strength after Ageing	
mils	mm.	lb. per sq. in.	kg. per sq. cm.
5	0.127	5.0	0.35
7	0.178	6.5	0.46
10	0.254	7.0	0.49

REQUIREMENTS FOR BLACK VARNISHED CLOTH

Electric Strength (Proof Test)

13. Note. The observed electric strength of varnished cloth is much lower when subjected to continuous application of the stress than when subjected to stresses of brief duration such as one minute or less. It is also lower at high temperatures than when cold.

* Pending the development of suitable methods of test for this characteristic on strip or tape, this test shall be made on larger sheet specimens from the varnished cloth from which the strip or tape is cut.

It should be noted that the value of the electric strength resulting from test (a) below does not give sufficient indication of the electric stress which the material can withstand when subjected to service conditions, such indication being given by a test in accordance with Clause 14.

While the electric strength proof test for brief periods (Clause 13 (a) and (b)) is useful for the purpose of quick check tests, the electric strength under prolonged stress while hot (Clause 14) is the value of chief importance to the designer of machinery and apparatus employing this type of insulation.

The electric strength test specified in (b) below checks the ability of material to withstand the mechanical tension without damage to the varnish film.

(a) **Electric Strength in Free State at 90° C.** The varnished cloth shall withstand for one minute without failure the voltage computed from the appropriate value in volts per mil specified in Table VIII, when tested as described in Appendix III.

Table VIII
Electric Strength at 90° C.
(One-minute Proof Stress)

Nominal Thickness		Volts per mil		Kilo volts per mm.	
mils	mm.	Large Electrodes *	Small Electrodes †	Large Electrodes *	Small Electrodes †
5	0.127	600	700	23.62	27.56
7	0.178	650	750	25.59	29.53
10	0.254	650	750	25.59	29.53

The material shall be deemed to comply with the requirements of this clause if it passes not less than four tests out of five.

(b) **Electric Strength of Bias-cut Strip or Tape not less than $\frac{3}{4}$ inch wide, under Mechanical Tension at 20° C.** The electric strength test under mechanical tension shall be carried out on bias-cut strip or tape only.

The strip or tape shall withstand for one minute without failure the voltage computed from the appropriate value in volts per mil specified in Table IX, when subjected to the appropriate mechanical tension given in Table IX and tested as described in Appendix III. .

* See Appendix III (a).

† See Appendix III (b).

When it is necessary to test strip or tape wider than 8 inches (76.2 mm.) the width shall be reduced so that the specimen can be tested in the apparatus described in Appendix III (b).

Table IX

Electric Strength of Bias-cut Strip or Tape under Mechanical Tension at 20° C.
(One-minute Proof Stress)

Nominal Thickness		Load		Volts per mil.	kV per mm.
mils	mm.	Pounds per inch width	Kilogrammes per centimetre width	Small Electrodes	Small Electrodes
5	0.127	3	0.54	750	29.53
7	0.178	4	0.72	800	31.50
10	0.254	5	0.89	850	33.46

The material shall be deemed to comply with the requirements of this clause if it passes not less than four tests out of five.

(c) **Electric Strength of Bias-cut Strip or Tape less than $\frac{3}{4}$ inch wide, under Mechanical Tension at 20° C.** The electric-strength test under mechanical tensions shall be carried out on bias-cut strip or tape only.

The strip or tape, of which the width is less than $\frac{3}{4}$ inch, shall withstand for one minute without failure the voltage computed from the appropriate value in volts per mil specified in Table X, when subjected to, and wound on a rod under the appropriate mechanical tension in Table X and tested as described in Appendix III.

Table X

Electric Strength of Bias-cut Strip or Tape less than $\frac{3}{4}$ inch wide, under Mechanical Tension at 20° C.
(One-minute Proof Stress)

Nominal Thickness		Load		Volts per mil	kV per mm.
mils	mm.	Pounds per inch width	Kilogrammes per centimetre width		
5	0.127	4	0.72	600	23.62
7	0.178	5	0.89	600	23.62
10	0.254	6	1.08	600	23.62

The strip or tape shall be deemed to comply with the requirements of this clause if it passes not less than four tests out of five.

Maintained Electric Stress (Proof Test)*

14. Varnished cloth of any thickness shall withstand for two hours without failure the appropriate voltage computed on the basis of 80 volts per mil (8.15 kV per mm.), when tested as described in Appendix IV.

The material shall be deemed to comply with the requirements of this clause if it passes two tests out of three.

Tensile Strength

15. The tensile strengths of varnished cloths in the warp and the weft directions respectively shall be as nearly equal as practicable. The tensile strengths in the several directions shall be not less than the appropriate value given in Table XI, when determined as described in Appendix V.

Table XI
Tensile Strength

Nominal Thickness		Minimum Tensile Strength					
		Straight Cut				Bias Cut	
		Warp		Weft			
mils	mm.	lb. per in. width	kg. per cm. width	lb. per in. width	kg. per cm. width	lb. per in. width	kg. per cm. width
5	0.127	25	4.46	15	2.68	15	2.68
7	0.178	30	5.36	20	3.57	20	3.57
10	0.254	35	6.25	25	4.46	25	4.46

The material shall be deemed to comply with the requirements of this clause if it passes not less than four tests out of five.

Tearing Strength*

16. The tearing strength of varnished cloth shall be not less than the appropriate value given in Table XII, when determined as described in Appendix VI.

* Pending the development of suitable methods of test for this characteristic on strip or tape, this test shall be made on larger sheet specimens from the varnished cloth from which the strip or tape is cut.

Table XII
Tearing Strength

Nominal Thickness		Tearing Strength (Double Tear)			
		Warp Tear (i.e., Travel of Tongue Parallel to Selvage across Weft Threads)		Weft Tear (i.e., Travel of Tongue Parallel to Weft Threads)	
mils	mm.	ounces	grammes	ounces	grammes
5	0.127	14	397	18	510
7	0.178	14	397	18	510
10	0.254	16	454	20	567

The material shall be deemed to comply with the requirements of the clause if it passes not less than four tests out of five.

Ageing *

17. The mean decrease in the bursting strength of varnished cloth, due to heat treatment, shall not exceed 60 per cent. computed *on the original mean value, when determined as described in Appendix VII.*

The bursting strength after ageing shall be not less than the appropriate value given in Table XIII.

Table XIII
Bursting Strength after Ageing

Nominal Thickness		Bursting Strength after Ageing	
mils	mm.	lb. per sq. in.	kg. per sq. cm.
5	0.127	5.0	0.35
7	0.178	6.5	0.46
10	0.254	7.0	0.49

APPENDIX I

Method of Conditioning Specimens for Test

The specimens shall be subjected for not less than 18 hours to a controlled atmosphere, relative humidity 75 per cent., at a

* Pending the development of suitable methods of test for this characteristic on strip or tape, the test shall be made on larger sheet specimens from the varnished cloth from which the strip or tape is cut.

temperature from 15° C. to 25° C. Every specimen shall be tested as soon as possible after removal from the controlled atmosphere, and in any case before three minutes have elapsed.

The specified relative humidity may be obtained by the use of lumps of common salt, which must be sprinkled occasionally with water. Sulphuric acid shall not be used for obtaining the specified relative humidity. The surface of the salt must be moist, care being taken that the lumps are not wholly covered by water, and must be large per unit volume of air space or the rate of attainment of equilibrium will be very slow.

In order to ensure that the relative humidity of the controlled atmosphere is maintained at the correct value, it is necessary either, that the temperature be kept constant, or that the air be circulated within the chamber.

The following method has been found satisfactory for maintaining the relative humidity of the controlled atmosphere constant.

The samples of varnished cloth are placed on a shelf half-way up in a cubical box with sides 24 inches (610 mm.) long. The floor of the box is nearly covered by a dish containing lumps of salt, which are occasionally sprinkled with water as indicated above. Air is circulated by means of a small fan over the salt up through holes cut at two corners of the shelf, over the samples and down through holes at the opposite corners of the shelf.

The humidity of the air, which may be measured by wet and dry bulb thermometers if the velocity of the air past them is greater than 3 metres per second, attains a constant value, unless the prevailing conditions are extreme, in about three minutes after the box has been closed and the fan has been started.

As an alternative to wet and dry bulb thermometers, which require a known air velocity, a dew-point thimble may be inserted in the box and used when the fan is not working. With either method a window is necessary to avoid opening the box.

The correctness of the humidity of the air should be checked from time to time.

APPENDIX II

Method for the Determination of Thickness

The thickness of the material shall always be measured in the free state, taking not less than four thicknesses of varnished cloth together, and employing a ratchet micrometer, the anvil and

spindle of which shall be not less than $\frac{3}{8}$ inch (9.53 mm.) and not more than $\frac{1}{2}$ inch (12.70 mm.) in diameter.

APPENDIX III

Method of Applying Proof Test for Electric Strength

The electric strength test shall be carried out with an alternating voltage of frequency 50 cycles per second, which shall be approximately sinusoidal. During the application of the test, the crest value (as would be determined by spark gap, by oscillograph or by other approved methods) shall be not more than 1.45 times the R.M.S. value. The R.M.S. value shall be measured by a suitable voltmeter connected to the high-voltage side of the testing transformer, or by means of a voltmeter used with a suitably calibrated potential transformer, or by means of a voltmeter used in conjunction with a special calibrated voltmeter-winding on the testing transformer.

The voltage shall be applied between the appropriate electrodes described below, and shall be increased at a uniform rate so that the required voltage is reached in about ten seconds. The value of voltage to be applied will be determined from the specified value of volts per mil given in the appropriate table, and the thickness of the specimen determined in accordance with Appendix II.

Electric-strength Test on Sheet, Strip or Tape in Free State at 90° C. The specimen shall be heated in an oven at a temperature of 90° C. ($\pm 2^\circ$ C.) for not less than one hour and not more than two hours before the electrodes are placed in position and shall be maintained at this temperature throughout the test. The electrode shall be heated to a temperature of 90° C. ($\pm 2^\circ$ C.) before being placed in contact with the specimen.

For testing sheet, the upper electrode shall consist of a solid cylinder of brass $1\frac{1}{2}$ inches (38.1 mm.) in diameter and $1\frac{1}{2}$ inches (38.1 mm.) high. The lower electrode shall consist of a brass block 3 inches (76.2 mm.) in diameter and 1 inch (25.4 mm.) thick. The sharp edges shall be removed from the electrodes, but the radius at the edge shall not exceed inch $\frac{3}{32}$ (0.794 mm.). The temperature shall be measured by a thermometer inserted in a hole in the top electrode and reaching to within $\frac{1}{2}$ inch (12.70 mm.) of the bottom.

For testing strip or tape, the apparatus described in (b) below shall be used. The temperature shall be measured by a thermo-

meter inserted in one of the holes in the apparatus provided for the upper electrode.

(b) **Electric Strength Test on Bias-cut Strip or Tape not less than $\frac{1}{4}$ inch wide, under Mechanical Tension at 20° C.** The specimens shall be conditioned in accordance with Appendix I before the electric strength test under mechanical tension is carried out.

The test shall be carried out at a temperature of 20° C. ($\pm 5^\circ$ C.) by means of the apparatus shown in Fig. 1. The clear length of tape between the clamps shall be 18 inches (457 mm.). The strip or tape shall be subjected to the appropriate load specified in Clause 8 (b) or 18 (b) for not less than one hour and not more than two hours before the voltage is applied.

Suitable apparatus for carrying out the electric strength test on strip or tape under mechanical tension is described below and is shown in Fig. 1. In this apparatus provision is made for five pairs of electrodes.

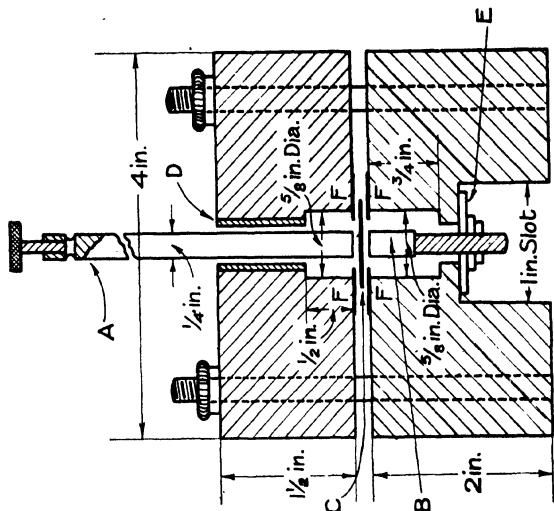
The tension shall be applied to the strip or tape for the specified time before the upper block is clamped down.

The electrodes shall consist of two brass rods each $\frac{1}{4}$ inch (6.35 mm.) diameter, with the edge rounded to a radius of $\frac{1}{32}$ inch (0.794 mm.). The weight of the upper rod shall be 0.1 pound (45 grammes), plus or minus 0.005 pound (2.27 grammes). The rods shall be placed with their common axis perpendicular to the surface of the strip or tape.

The five lower electrodes are fastened rigidly to a brass strip which runs the whole length of the apparatus, and is connected to the "earthed" terminal of the supply. The rest of the apparatus consists of two blocks of impregnated wood, one $9 \times 4 \times 2$ inches ($229 \times 102 \times 51$ mm.), the other $9 \times 4 \times 1\frac{1}{2}$ inches ($229 \times 102 \times 88$ mm.).

The lower block has a slot $1 \times \frac{7}{8}$ inch (25.4×22.2 mm.) running along the length, and into this slot the brass strip mentioned above is fixed. Each of the lower electrodes protrudes upwards through the wood, standing centrally in a $\frac{9}{16}$ inch (14.29 mm.) diameter hole drilled in the block, the top of the electrodes being absolutely flush with the top level of the block. These electrodes are $1\frac{1}{2}$ inches (88 mm.) apart.

The upper block is clamped firmly over the lower block. Five holes are drilled in it, the upper half of the hole being fitted with a brass bush $\frac{1}{4}$ inch (6.35 mm.) (and clearance) in diameter, the lower half being $\frac{5}{8}$ inch (15.88 mm.) in diameter. When the upper electrodes are inserted into these holes, they rest on the lower

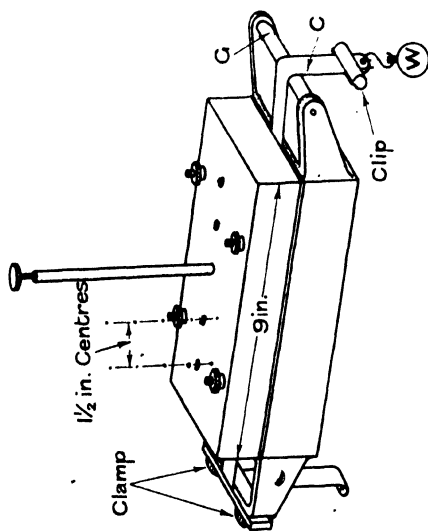


(b) Section of apparatus through electrodes with top slightly raised.

E. Brass strip 1 inch wide connecting all lower electrodes.

F. Pieces of varnished cloth strip overlapping edges of sample.

G. Roller $\frac{3}{8}$ inch diameter. Free to revolve.



(a) Apparatus with sample set up for test under mechanical tension.

A. Upper electrode. To be an easy fit in bush D.

B. Lower electrode.

C. Sample under test.

D. Brass bush. Inside diameter just sufficient to clear $\frac{1}{4}$ inch rod.

FIG. 1. Electrode Apparatus for Electric-Strength Test on Strip or Tape under Mechanical Tension.

NOTE.—The apparatus shown in Fig. 1 is based on that described by the American Society for Testing Materials (*see* Appendix to A.S.T.M., serial designation D.149-27 T).

electrodes, which take the weight of the upper electrodes. Each upper electrode is fitted with a terminal by means of which connection is made to the high voltage of the supply.

The sample under test lies between the electrodes, and is firmly

clamped in position by the two blocks. In order to prevent flashover round the sample, strips of varnished cloth are placed along the length of the testing apparatus on both upper and lower blocks. The edges of the strip or tape under test are clamped firmly between these strips when the top is in position, but no overlapping is allowed between these and any of the electrodes.

The strips of varnished cloth must be examined after every sample has been tested, and must be replaced at intervals, especially when very narrow strip or tape, or strip or tape having a high breakdown voltage, is being tested.

The electrodes need frequent attention, as they become pitted, and it is not sufficient to clean them with emery cloth or by similar means; they must be turned in a lathe in order to maintain the specified rounding of the edges.

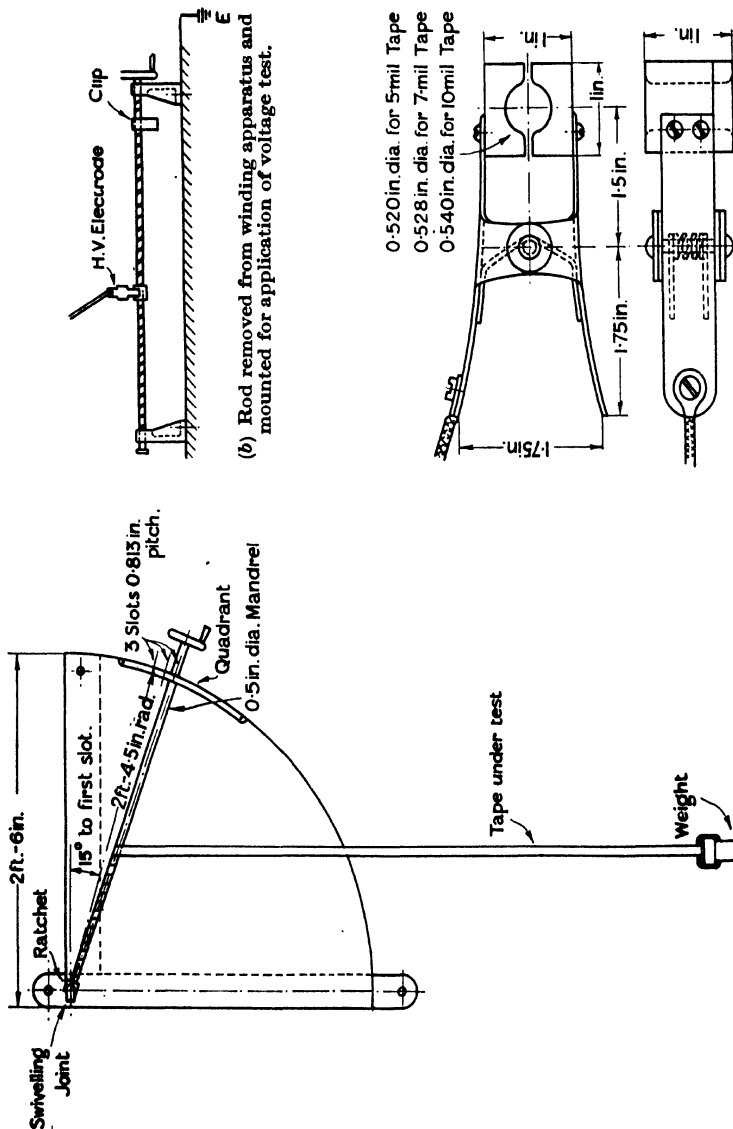
(c) **Electric-strength Test on Bias-cut Tape less than $\frac{3}{4}$ inch wide, under Mechanical Tension at 20° C.** The specimen shall be conditioned in accordance with Appendix I before the electric strength test under mechanical tension is carried out.

The test shall be carried out at a temperature of 20° C. ($\pm 5^\circ$ C.) after the tape has been wound on a rod by means of the apparatus illustrated in Fig. 2.

The steel rod used shall be $\frac{1}{2}$ inch in diameter and 28 inches long, fitted with a slot at one end for anchoring the end of the tape, and a suitable handle at the other end for rotating the rod during the taping process. The rod shall be clean and smooth. One end of the rod shall be attached to a universal joint and the other inserted in the special slot on the quadrant provided for the given width of tape. The angles of inclination of the rod for various widths of tape shall be as follows :—

Width of Tape		Inclination of Rod
inch.	mm.	
$\frac{1}{4}$	12.70	15°
$\frac{3}{8}$	15.86	16 $\frac{1}{2}$ °
$\frac{1}{2}$	19.05	18°

A sample of tape approximately 70 inches long shall be anchored by inserting one end in the slot provided on the rod, and subjected to tension by fastening a suitable weight to the other end to give the load specified in Table IV or X corresponding to the thickness



(a) Apparatus for winding the tape on to the mandrel.

Fig. 2. Apparatus for Electric-Strength Test on Bias-cut Tape less than $\frac{1}{4}$ inch wide, under Mechanical Tension.

and width of tape. The tape shall be subjected to the specified tension for a period of five minutes.

The rod shall then be slowly and steadily rotated, thereby producing a uniformly taped layer extending from one end of the rod to the other, each turn overlapping half of the total width of the preceding turn, less $\frac{1}{16}$ inch, thus leaving a single-thickness helix of tape $\frac{1}{8}$ inch wide. This is automatically done by supporting the rod at a definite inclination to the horizontal provided for in the apparatus.

The last turn of the tape shall then be anchored to the rod by a suitable clip and the weight removed. The taped rod shall then be removed for the electric strength test. (See Fig. 2 (b)).

The voltage shall be applied between a suitable split cylindrical metal clamp, 1 inch long (Fig. 2 (c)), sprung on to the taped bar as the outer electrode, and the rod as the inner electrode. The sharp edges shall be removed from the electrodes, but the radius at the edges shall not exceed $\frac{1}{32}$ inch.

APPENDIX IV

Method for Carrying Out Maintained Electric Stress (Proof) Test

The specimen shall consist of a pad built up of sufficient layers of varnished cloth, $5 \times 4\frac{1}{2}$ inches (127×114 mm.), to a total thickness of approximately 30 mils (0.76 mm.). The individual pieces of varnished cloth and two felt pads approximately $5 \times 4\frac{1}{2}$ inches (127×114 mm.) by $\frac{1}{2}$ inch (12.70 mm.) thick shall be heated for not less than two hours and not more than three hours in an oven at a temperature between 100° C. and 105° C., air being allowed free access between the pieces of cloth and between the felt pads. The felt of which the pads are made shall be approximately $\frac{1}{2}$ inch (12.70 mm.) thick, and the weight in the dry condition shall be approximately $6\frac{1}{2}$ ounces per square foot * (1,985 grammes per square metre).

The pieces of varnished cloth shall be built up into the pad forming the specimen, and an electrode, which shall consist of tin foil between one and two mils (0.08 and 0.05 mm.) thick, $8\frac{1}{2} \times 8$ inches (88×76 mm.) in area, shall be placed on each side of the specimen, care shall be taken to exclude air from between the pieces of varnished cloth and from between the electrodes and the specimen when pressing these together. One of the dried felt pads

* Information on the source of supply of suitable felt can be obtained from the Director of the British Engineering Standards Association.

shall be placed on each side of the specimen and electrodes for thermal jacketing. The whole shall then be placed in the testing oven between two polished copper or brass blocks, each $4 \times 8\frac{1}{2}$ inches (102×88 mm.) by $1\frac{3}{8}$ inches (35 mm.) thick, the metal blocks having been previously heated to a temperature of 90°C . ($\pm 2^{\circ}\text{C}$.) in the oven. The period elapsing between the removal of the pieces of varnished cloth from the conditioning oven and the assembling of the specimen between the electrodes, felt pads and brass blocks in the testing oven shall not exceed five minutes.

The arrangement of specimen, electrodes, connections, felt pads and metal blocks is shown in Fig. 3.

The temperature of the testing oven shall be maintained at 90°C . ($\pm 2^{\circ}\text{C}$.) throughout the test. After thirty minutes an alternating voltage, frequency 50 cycles per second, computed as specified in Clause 8 or 18, shall be applied between the electrodes. The specimen shall withstand this voltage for two hours without failure.

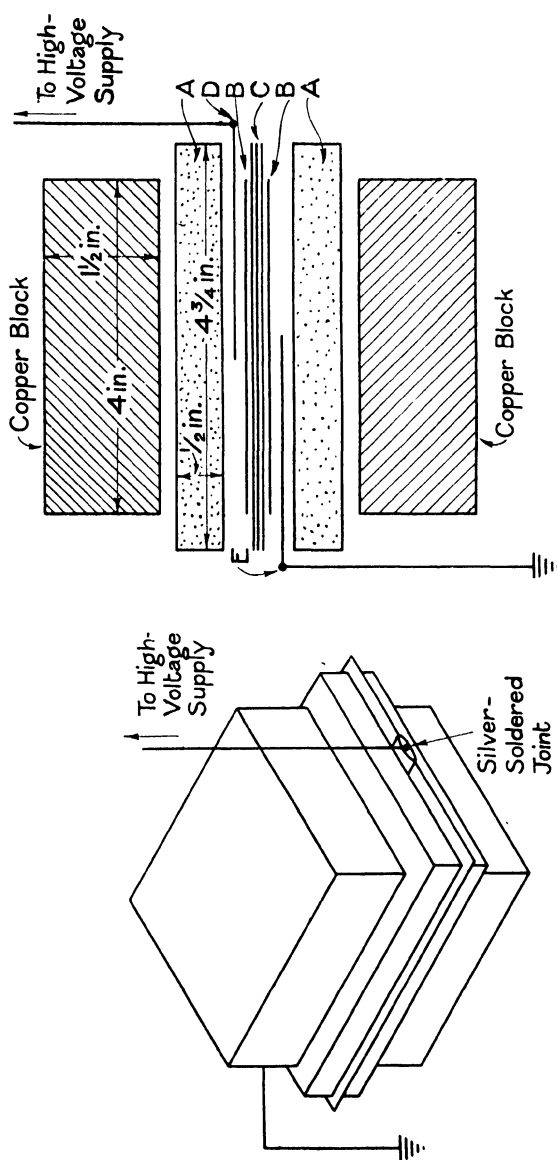
APPENDIX V

Method for the Determination of Tensile Strength

The specimen shall be conditioned in accordance with Appendix I before the tensile strength is carried out.

In the case of cloth, ten specimens 2 inches (50.8 mm.) wide shall be cut in the direction of the warp, and ten specimens 2 inches (50.8 mm.) wide shall be cut in the direction of the weft of the cloth. The specimens shall be cut in such a manner as to be representative of the bulk of the varnished cloth. No two specimens cut in the same direction shall contain the same longitudinal threads. In the case of strip or tape, ten specimens shall be tested. If the width of the strip or tape exceeds 2 inches (50.8 mm.) the width of the specimen shall be reduced to 2 inches (50.8 mm.). Each specimen shall be of such a length that the unstretched length of the varnished cloth between the jaws of the testing machine is not less than 6 inches (158 mm.).

The test shall be carried out at temperatures between 15°C . and 25°C . The loads shall be applied at a uniform rate, and the time taken to reach the specified breaking loads from the commencement of the application of the load shall be approximately one minute. If the specimen breaks unevenly, or in or at a jaw of the testing machine, owing to incorrect clamping, a duplicate test shall be carried out on another specimen including the same threads.



(a) Test sample assembled with electrodes, pads and metal blocks.

A. Hair-felt pad.

B. Tin-foil electrodes, $3\frac{1}{2} \times 3$ inches.

C. Sample under test.

(b) Section showing various parts separated.

D. High-voltage connection. Copper foil not exceeding 5 mils thick, with silver-soldered joint to withstand high temperatures.

E. Earth connection. Similar to D.

FIG. 3. Arrangement of Specimen, Electrodes, etc., for Maintained Electric Stress (Proof) Test.

APPENDIX VI

Method for the Determination of Tearing Strength

The specimen shall be conditioned in accordance with Appendix I before the tearing strength test is carried out.

The resistance to tearing shall be determined by the load required to tear a tongue 2 inches (50.8 mm.) wide commencing from holes $\frac{3}{32}$ inch (2.38 mm.) diameter punched out of the varnished cloth (see Fig. 4). Ten tests shall be carried out in the

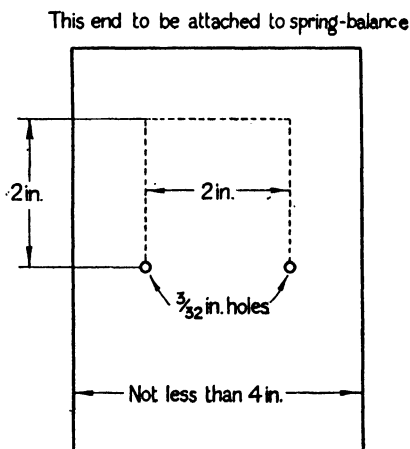


FIG. 4. Specimen for Tearing Test.

direction of the warp and ten tests in the direction of the weft of the cloth. Each specimen shall be of such length that a tear not less than 4 inches (102 mm.) long can be obtained. The width of the specimen shall be not less than 4 inches (102 mm.).

The test shall be carried out at a temperature between 15° C. and 25° C. as follows :—

The upper end of the specimen shall be gripped in a clamp the full width of the specimen. The clamp shall be attached to a spring balance. The tongue already cut out, as shown by the dotted lines in Fig. 4, shall be gripped and attached to the mechanism for applying the load (preferably driven by geared motor). The load shall be applied in such a manner that the varnished cloth tears at a uniform rate, which shall be approximately 12 inches (800 mm.) per minute. The readings of the spring balance shall be observed for the first 2 inches (50.8 mm.)

of the tear, and the average of all the varying peak values of the pull shall be deemed to be the tearing strength of the specimen.

APPENDIX VII

Method for the Determination of Ageing

Three specimens of varnished cloth approximately 9 inches (230 mm.) square shall be conditioned in accordance with Appendix I, and the bursting strength of each specimen shall be determined as described below within three minutes of the removal of the specimen from the conditioning chamber. The mean value obtained from the three specimens shall be deemed to be the bursting strength of the varnished cloth.

Three further specimens of varnished cloth approximately 9 inches (230 mm.) square shall be suspended in a uniformly heated air oven and maintained at a temperature of 110° C. ($\pm 2^\circ$ C.) for twenty-four hours. The specimens shall be conditioned in accordance with Appendix I, and their bursting strength shall be determined as described below, within three minutes of their removal from the conditioning chamber. The mean value obtained from the three specimens shall be deemed to be the bursting strength of the varnished cloth after ageing.

The bursting strength test shall be carried out by means of the apparatus shown in Fig. 5.

The varnished cloth shall be clamped flat, but without tension between the rubber insertion rings fitted on top of the drum so as to make an air-tight joint. Air shall be pumped into the drum at such a rate that the pressure on the varnished cloth diaphragm is increased gradually at a rate between 25 and 30 pounds per square inch (1.8 and 2.1 kg. per sq. cm.) per minute until failure occurs. The pressure gauge shall be fitted with a pointer which will continue to indicate the maximum pressure reached in the test until it is released by the operator.

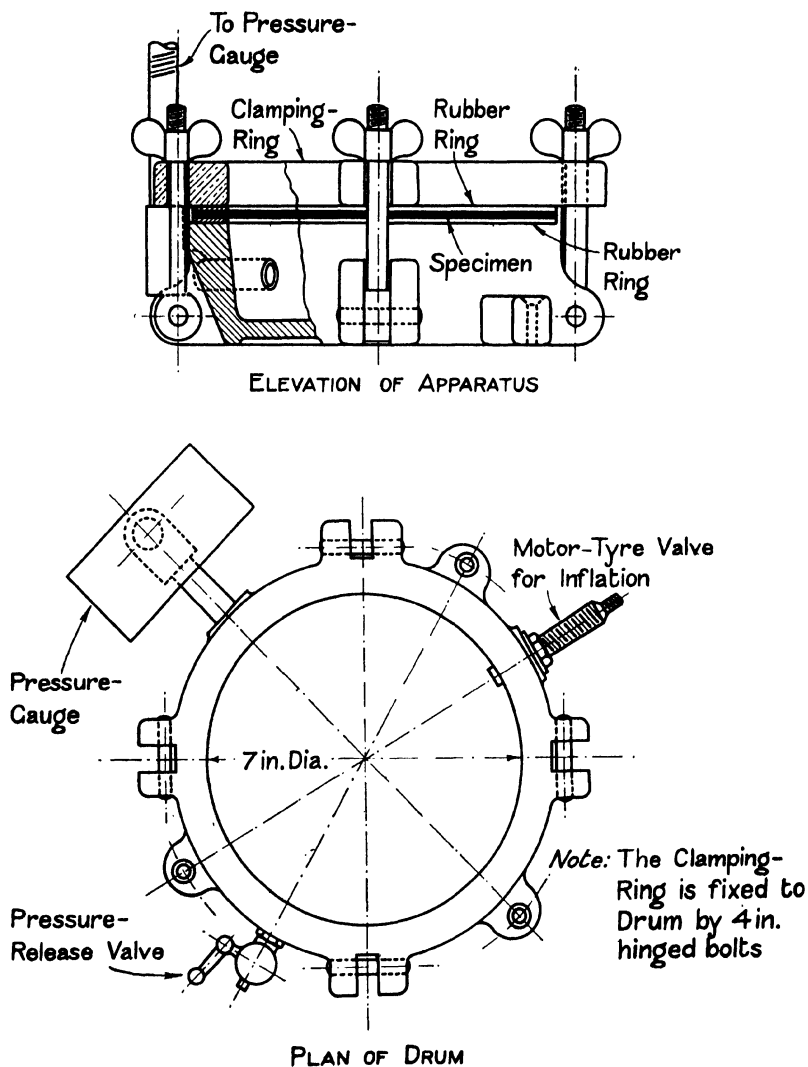


FIG. 5. Apparatus for Measuring the Bursting Strength of Varnished Cloth.

AMERICAN SOCIETY FOR TESTING MATERIALS *
260 S. Broad Street, Philadelphia, 2 Pa.

**TENTATIVE METHODS OF TESTING VARNISHED CLOTHS
AND VARNISHED CLOTH TAPES USED IN ELECTRICAL
INSULATION (1)**

A.S.T.M. Designation : D 295—43 T

ISSUED, 1928 ; REVISED, 1929, 1932, 1933, 1934, 1936, 1937,
1938, 1943. (2)

This Tentative Standard of the American Society for Testing Materials is, under its Regulations, subject to annual revision. Suggestions for revision should be addressed to the Society, 260 S. Broad Street, Philadelphia 2, Pa.

1. Scope. These methods cover procedures for the testing of varnished cloths and varnished cloth tapes, including glass fabrics (Note), to be used as electrical insulation and are directly applicable to both the "straight-cut" and "bias-cut" materials, unless otherwise stated in the method.

NOTE.—Only those methods which carry a notation to that effect have been approved for testing glass fabrics.

Sampling

2. Selecting Rolls. (a) Shipments of varnished cloth and varnished cloth tapes shall be sampled as specified in Paragraphs (b) and (c). The rolls or pads shall be selected in such a manner as to be representative of the shipment.

(b) *Cloth.* One roll shall be selected from each ten rolls in a shipment of full-width varnished cloth. The minimum number of rolls selected from any shipment shall be two.

(c) *Tape.* At least one roll or pad shall be selected from each 1,000 rolls or pads in a shipment of varnished cloth tape. The minimum number of rolls or pads selected from any shipment shall be ten.

3. Selecting Samples. (a) Except for tape shipped packed in oil,

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1. Under the standardisation procedure of the Society, these methods are under the jurisdiction of the A.S.T.M. Committee D-9 on Electrical Insulating Materials.

2. Latest revision accepted by the Society at annual meeting, June, 1943.

not less than two turns of cloth or six turns of tape from each roll or pad selected for sampling shall be torn off and discarded before the samples are selected. The number of samples required for purpose of tests shall then be cut across the entire width of each roll or pad. The length of the samples shall be not less than 91 cm. (86 in.) for straight-cut material, from seam to seam for sewed bias-cut material, and from jointed-selvedge to jointed-selvedge for seamless bias-cut material.

NOTE 1.—Specimens of bias-cut materials cut from the above samples shall exclude seams and jointed-selvedges from the test areas.

NOTE 2.—If it is desired to test the seams or jointed-selvedges for breaking strength, additional specimens will have to be cut so that the seams or jointed-selvedges are in the centre of the specimens.

(b) From shipments such as sheets of cloth or strips of tape, the samples shall be representative of the shipment and shall be taken in accordance with Paragraph (a).

4. Conditioning. (a) The roll of cloth or tape from which specimens are to be cut shall be conditioned for a minimum of two hours at a room temperature between the limits of 20° to 80° C., no humidity control.

(b) Specimens to be tested in the as-received condition for breaking strength, elongation, and dielectric strength shall be removed from the roll as required and tested immediately.

(c) If the humidity of the room is above 65 per cent., the roll of tape shall be kept in a cabinet whose relative humidity is maintained between 60 to 65 per cent.

(d) In the event of dispute, the test specimens shall be conditioned for forty-eight hours at a temperature between 20° to 80° C. and at a relative humidity between 60 to 65 per cent.

Thickness

5. Test Specimens. Test specimens shall consist of samples selected in accordance with Section 3.

6. Procedure. (a) The thickness shall be measured in accordance with Method B of the Standard Methods of Test for Thickness of Solid Electrical Insulation (A.S.T.M. Designation : D 874) of the American Society for Testing Materials, (8) except as specified in the following Paragraphs (b) to (d).

(b) In making thickness measurements, only one layer of material shall be used.

(c) In the case of cloths, ten measurements equally spaced across the width of the specimen shall be taken and the thickness of the cloth shall be the average of the ten measurements.

(d) In the case of tapes, unless otherwise specified, ten measurements equally spaced along the length of each specimen shall be taken and the thickness of the tape shall be the average of the ten measurements.

NOTE.—The average thickness, as obtained in Section 14 for the dielectric strength test, may be conveniently used instead of the separate test described above.

7. Report. The report shall include the average, maximum, and minimum thickness in inches.

Breaking Strength

8. Apparatus. (a) A testing machine (4) of the dead-weight pendulum type shall be used. The machine shall preferably be power driven.

(b) The capacity of the machine shall not exceed 118 kg. (250 lb.).

(c) The machine shall be graduated to read 1 lb. or 1 kg. or less per scale division for testing specimens breaking at 22.7 kg. (50 lb.) or over, and to 0.5 lb. or 0.5 kg. or less for testing specimens breaking under 22.7 kg. (50 lb.).

9. Test Specimens. Specimens cut from the full width cloth or from tapes over 2.54 cm. (1 in.) in width shall be 2.54 cm. (1 in.) in width and not less than 35.5 cm. (14 in.) in length. For tape having a nominal width of 2.54 cm. (1 in.) or under, the specimens shall be of the original width and shall be not less than 35.5 cm. (14 in.) in length.

NOTE.—If it is desired to test the seams or jointed-selvages of bias-cut materials for breaking strength, specimens obtained as described in Note 2, Section 8 (a) shall be clamped in the testing machine so that the seams or jointed-selvages are midway between the two jaws. When testing, all readings obtained when the specimen breaks away from the seam or jointed selvage shall be rejected.

10. Number of Specimens. (a) In the case of straight-cut cloths, ten specimens shall be cut in the direction of the warp

4. This apparatus is the same as that used for the testing of paper and is described in Section 16 of the Tentative Methods of Sampling and Testing Untreated Paper Used in Electrical Insulation (A.S.T.M. Designation : D 202), 1942 Book of A.S.T.M. Standards, Part III., p. 1187.

threads and ten in the direction of the filling threads from samples selected in accordance with Section 8.

(b) In the case of bias-cut cloths, ten specimens shall be cut in the direction of the length from samples selected in accordance with Section 8.

(c) In the case of tapes, one specimen shall be cut from each roll selected in accordance with Section 2 (c).

11. Procedure. (a) The ratio of the clearance distance between jaws to the width of the specimen shall not be less than 5 to 1 nor more than 10 to 1.

(b) The rate of travel of the movable jaw shall be constant and preferably 30.5 cm. (12 in.) per minute, but it may be within the limits of 28 and 33 cm. (11 and 13 in.) per minute provided it is constant.

(c) All readings obtained when the specimen breaks at or in the jaws shall be rejected.

12. Report. (a) The breaking strength of a roll shall be the average of the breaking loads of all the specimens tested from the roll. The report shall include the average, maximum, and minimum breaking loads in kilograms or pounds together with the width of the specimens and the nominal thickness.

(b) In the case of straight-cut cloths, the breaking strength of the warp threads and the filling threads shall be reported separately.

Dielectric Strength

Short-Time and Step-by-Step Tests

13. Purpose. The purpose of this test is to determine the dielectric strength of varnished cloths and varnished cloth tapes, including glass fabrics, when subjected to a short-time or step-by-step test.

14. Dielectric Strength. (a) The dielectric strength shall be determined in accordance with the Tentative Methods of Test for Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies (A.S.T.M. Designation : D 149) of the American Society for Testing Materials, (5) except as specified in the following Sections 15 to 20.

(b) Dielectric strength tests may be applied to specimens of the material as-received, and on specimens from the elongation, resistance to oil, and humidity tests.

15. Apparatus. (a) For the testing of narrow specimens, such as tapes, it is necessary to use a special form of testing device, whereby the test specimen shall be clamped under pressure in order to prevent flashover around the edges of the material. Two forms of testers are described in the Appendix.

16. Test Specimens. (a) In the case of cloths, a specimen at least 10·16 cm. (4 in.) in width shall be cut diagonally from corner to corner from a sample selected in accordance with Section 3.

(b) In the case of tapes, the specimens shall be samples selected in accordance with Section 3.

17. Surrounding Medium. Tests shall be made in air unless the material is to be used under oil, in which case the material may be tested under oil.

18. Conditioning. Specimens shall be conditioned in accordance with Section 4.

19. Procedure. (a) Tests shall be made by either the short-time test or the step-by-step test, or by both methods.

(b) In the short-time test, voltage shall be increased at the rate of 0·5 kV per second.

(c) In tests made by the step-by-step test, each step shall be of twenty seconds' duration. Voltage shall be increased by the following increments :—

Nominal Thickness of Tape

8 mils or less	.	.	.	.	.	250 v.
Over 8 mils	.	.	.	.	.	500 v.

The starting voltage shall be adjusted to the nearest even 250 or 500 volts, depending on the increment of increase. The starting voltage should preferably be based upon the breakdown voltage in the short-time test, as provided in Tentative Methods D 149. (5) Where this may not be feasible or convenient, a starting voltage may be selected as the result of test experience, of such a value that at least three testing steps are obtained prior to breakdown.

20. Report. The report shall include the following :—

(a) The test method used for determining the dielectric strength.

(b) The average dielectric strength in volts per mil and any other values of dielectric strength as required by the materials, specifications, and

(c) The temperature at which the tests were made.

Endurance Dielectric Strength

21. Purpose. The purpose of this test is to obtain some idea of

the relative dielectric strength of various materials when subjected to electrical stress for relatively long periods at high temperature.

22. Test Specimens and Apparatus. (a) The specimens shall be made by wrapping the material in tape form with one-quarter lap, one-half lap, or butt-jointed, or in sheet form, on brass tubes. For sheets and for tape up to $1\frac{1}{2}$ inch in width, the tubes shall be about 36 inches in length and 1 inch in outside diameter. For tapes wider than $1\frac{1}{2}$ inch, the tubes shall be 2 inches in outside diameter. The sample shall be built up to the desired thickness, simulating practical conditions, winding all layers of tape in the same direction.

(b) A smooth layer of metal foil shall then be wrapped over the insulation for a distance of 24 inches, leaving 6 inches of insulation uncovered at each end of the tube. The metal foil shall be bound in place with a wrapping of adhesive tape which shall extend the full length of the tube in order to protect the insulation at the end from corona discharge.

(c) A thermocouple shall be applied to the metal foil near the centre of the tube and held in place by the adhesive tape.

23. Procedure. (a) The specimens shall be mounted in an oven and a temperature of 100°C . (212°F .) maintained during the test. Provision shall be made for so mounting the specimen that the tube may be connected to the high-voltage side of the circuit, with the metal foil sheath and thermocouple connected to ground.

(b) A voltage equal to 10 per cent. of the breakdown voltage (to the nearest kilovolt) obtained in the short-time test shall be applied and maintained for thirty minutes. The voltage shall then be increased by steps of 20 per cent. of the initial value until puncture occurs, the voltage being held at each step for thirty minutes.

(c) The temperature of the sample as indicated by the thermocouple shall be observed at intervals during the test and recorded at the end of each thirty-minute period. It will be found that the temperature rises gradually until just before breakdown when the temperature increases rapidly. During this latter period, temperature readings shall be recorded at frequent intervals.

24. Report. (a) The results shall be plotted using time, expressed in hours, as abscissæ, and temperature, in degrees Centigrade, as ordinates. In addition to time as abscissæ, the values of applied kilovolts shall be indicated, since the value of

kilovolts increases uniformly with time. The significant values to be taken from the curve and reported are as follows :—

1. Duration of test ;
2. Breakdown voltage ;
3. Temperature of specimen at breakdown ; and
4. Rate of temperature rise during test.

(b) The report shall also include a description of the specimen and its preparation, the thickness of the insulation, and the number of layers of insulation.

Elongation

(In the Case of Bias-Cut Material)

25. Purpose. The purpose of this test is to determine the effect of mechanical tension on bias-cut varnished cloths and tapes. This test is not applicable to tapes of less than 1.27 cm. (0.5 in.) in nominal width.

26. Apparatus. The apparatus shall consist of a pair of clamps for gripping the ends of the specimen. The clamps shall be not less than 5.08 cm. (2.0 in.) in width, and one shall be provided with means for attaching to a fixed support and the other with means for affixing suspended weights. A suggested form of clamp is shown in Fig. 1.

27. Test Specimens. (a) In the case of bias-cut cloths, specimens shall be cut in the direction of the length from the samples selected in accordance with Section 3. They shall not exceed 8.81 cm. (1.5 in.) in width and shall be at least 91 cm. (36 in.) in length.

(b) In the case of bias-cut tapes, specimens shall be samples selected in accordance with Section 3 and they shall not exceed 3.8 cm. (1.5 in.) in width. Tapes of greater width than this shall be cut to 3.8 cm. (1.5 in.) or less before testing.

NOTE.—Strips of Scotch cellulose tape make a satisfactory method for marking the gage length on the elongation test specimens.

28. Procedure. (a) A gage length of 50 cm. shall be marked on the test specimen and the specimen shall be fastened between two suitable clamps so that the gage length is centrally located

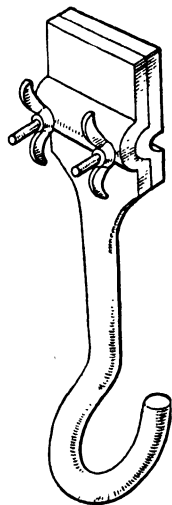


FIG. 1. Clamp for Elongation Test.

between the clamps. The clearance distance between each gage line and the adjacent clamp shall be not less than 10 cm.

(b) The test specimen shall be weighed with a specified load M (including the weight of the clamp) and at the end of thirty-five minutes the distance L between gage lines shall be measured and the load then removed.

29. Dielectric Strength after Elongation. After at least 20 min., but not more than one hour, following the removal of the load, five puncture voltages shall be taken within the gauge length of the specimen in accordance with Section 14, using only the short-time test described in Tentative Methods D 149 (5). The dielectric strength shall be calculated on the basis of the average thickness of the specimen determined immediately before the dielectric breakdown test.

30. Calculation. The percentage elongation shall be calculated as follows :—

$$\text{Elongation, per cent.} = \frac{L - 50}{50} \times 100$$

where

L = distance in centimetres between gage lines at end of the test.

31. Report. The report shall include the following :—

- (a) The load in pounds per inch width at tape ;
- (b) The percentage elongation ;
- (c) The average dielectric strength in volts per mil after elongation ; and
- (d) The temperature of the room during the elongation test.

Power Factor and Dielectric Constant

32. Purpose. The purpose of this test is to determine the power factor and dielectric constant of varnished cloths and varnished cloth tapes, including glass fabrics, at frequencies not exceeding 70 cycles per second.

33. Definitions and Theory of Test. The definitions of dielectric power factor, dielectric constant, and related terms, and the theory of test shall be as given in the Tentative Methods of Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (A.S.T.M. Designation : D 150 of the American Society for Testing Materials). (6)

5. 1942 Book of A.S.T.M. Standards, Part III., p. 1141.

6. 1942 Book of A.S.T.M. Standards, Part III., p. 1148.

84. Electrodes. Flat, rigid, guarded electrodes, not over 10 square inches in area, of such size as to give the bridge sufficient sensitivity to detect readily a change in power factor of 0.0005, shall be used. The specimen shall extend beyond the guard electrode for a distance of at least four times the thickness of the specimen. The pressure shall be not less than 10 nor more than 20 p.s.i.

85. Test Specimens. The test specimen may be tested in one thickness. Petrolatum may be used to avoid ionisation. The petrolatum shall have a power factor at 80° C. of not exceeding 0.02 at 60 cycles, or a resistivity not less than 10^{12} ohms per centimetre cube at 80° C.

86. Conditioning. The test specimens shall be conditioned in one thickness by heating to $105 \pm 3^\circ$ C. for one hour, without vacuum, and then for two hours at the same temperature in a vacuum having an absolute pressure not exceeding 1 mm. of mercury.

87. Procedure. (a) Tests shall be made at room temperature of 25° to 30° C., and at 80° C. $\pm 1^\circ$ C. The conditioned specimens shall be tested within five minutes after removal from the vacuum container. The voltage gradient shall be 50 volts per mil. The method of measurement shall conform to that described in Tentative Methods D 150. (6)

(b) Three specimens shall be tested and the values obtained averaged.

88. Report. The report shall include the following:—

(a) *Test Conditions.* The frequency in cycles per second, the temperature in degrees Centigrade, relative humidity in per cent., the conditioning of the specimen, size of electrodes, pressure on electrodes, and voltage gradient in the dielectric while under test.

(b) *Test Specimen.* Capacitance of specimen in micro-microfarads, effective area of specimen electrodes, and average thickness of specimen between electrodes.

(c) Power factor, dielectric constant, and loss factor of each specimen, and the average.

(d) Method of measurement.

Insulation Resistance

89. Procedure. The insulation resistance of varnished cloths and varnished cloth tapes, including glass fabrics, shall be deter-

mined in accordance with the Standard Methods of Test for Insulation Resistance of Electrical Insulating Materials (A.S.T.M. Designation : D 257). (7) The test specimen shown in Fig. 1 of A.S.T.M. Methods D 257 shall be used.

Resistance to Oil

40. Purpose. The purpose of this test is to determine the effect of oil on the varnish film and dielectric strength of the cloths or tapes, including glass fabrics.

41. Test Specimens. One specimen 30.5 cm. (12 inches) in length and not exceeding 3.8 cm. (1.5 in.) in width shall be cut from each of the rolls selected in accordance with Section 2.

42. Procedure. The specimens shall be immersed for 15 minutes in a specified oil maintained at a temperature of from 97° to 108° C. At the end of this time, the specimens shall be removed from the oil, allowed to cool for at least thirty minutes to room temperature and any excess oil removed by placing the specimens between blotters without any sliding.

43. Examination. The varnish film shall be examined for disintegration in the oil and flaking either in the oil or on the blotter. Disintegration in the oil may be detected by examination of the used oil for turbidity.

NOTE.—The oil may be considered turbid if a sample of used oil filtered through filter paper is distinctly less transparent than an unfiltered sample of the unused oil when the two samples, in identical containers, are held in front of a diffused light. Flaking along the cut edges of tapes shall not be considered as disintegration of the varnish film.

44. Dielectric Strength. Specimens which have been allowed to cool at least thirty minutes may be tested for dielectric strength any time within a period of four hours after removal from the oil. Five puncturing voltages shall be taken on the specimens in accordance with Section 14, using only the short-time test described in Tentative Methods D 149. (5) The dielectric strength shall be calculated on the basis of the average thickness of the specimen determined immediately before the dielectric breakdown test.

45. Report. The report shall include the following :—

(a) The type of oils used (preferably including the flash point determined in accordance with the Standard Method of Test for

7. 1942 Book of A.S.T.M. Standards, Part III., p. 888.

5. 1942 Book of A.S.T.M. Standards, Part III., p. 1141.

Flash and Fire Points by Means of Open Cup (A.S.T.M. Designation : D 92 of the American Society for Testing Materials) ; (8)

- (b) The temperature of the oils ;
 - (c) Results of the physical examination of the film (Section 43) ;
 - (d) The percentage increase in average thickness due to oil tests ;
- and
- (e) The average dielectric strength in volts per mil after the oil tests.

Weight

46. Procedure. Specimens of varnished cloths or varnished cloth tapes, including glass fabrics, of sufficient size to weigh not less than 5 g. (0.18 oz.) shall be accurately weighed on an analytical balance and the weight shall be reported on some commercial unit basis such as the weight per square yard, the weight per gross yard per 1 inch in width, or the weight per roll.

Threads per Inch

47. Procedure. The count or threads per inch of the varnished cloth or varnished cloth tape, including glass fabrics, shall be determined separately on the warp and filling by counting in a space of not less than 1 inch (2.54 cm.) in at least five different places in the sample strip (or strips). The average of the five determinations shall be the count.

48. Report. The results of the warp count and the filling count shall be reported separately as threads per inch.

NOTE 1.—The warp threads in straight-cut materials are the threads which are parallel with the length dimension, while in bias-cut materials the warp threads are parallel with the seams and jointed selvages.

NOTE 2.—Before counting black varnished materials it will be necessary to remove the varnish film with a knife blade or other suitable instrument. Liquid varnish removers are unsuitable for this purpose as they cause a swelling of the fibres and a shrinkage of cloth with a consequent increase in threads per inch ; therefore, the films must be removed mechanically.

APPENDIX

Apparatus for Making Dielectric Strength Tests on Insulating Tape

A1. Single Shot Tester. Fig. 2 illustrates a single-shot tester for making dielectric strength tests on insulating tape. In this device the tape is held under pressure between rubber washers

while the voltage is applied, the pressure being supplied by compressed air operating on a piston *b* in a cylinder *a*. The piston is connected to the upper electrode *c*. The lower electrode *c'* is mounted on the insulated base. The electrodes terminate in $\frac{1}{4}$ -inch brass rods having flat ends with edges rounded to a radius of $\frac{1}{32}$ inch. These electrode rods move against light springs. This insures a positive contact between electrode and tape. The

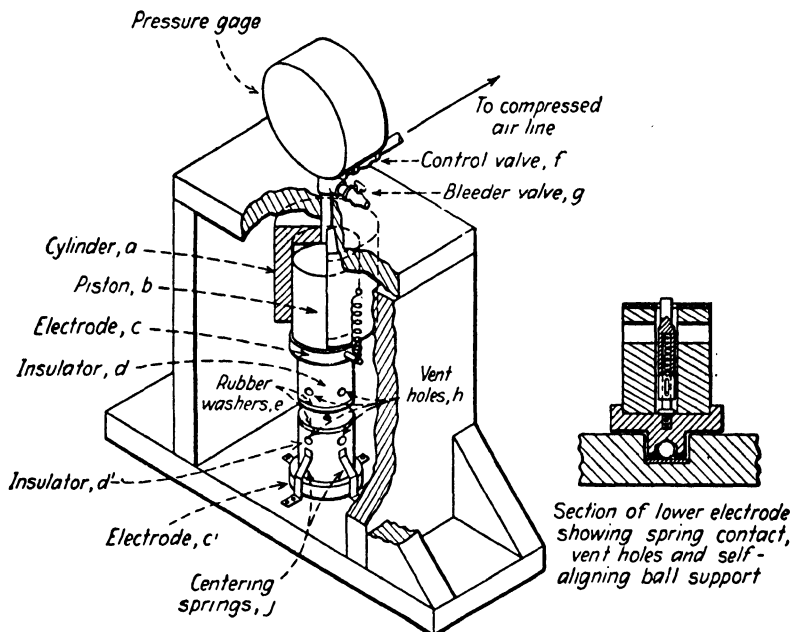


FIG. 2. Single-Shot Tester for Dielectric Strength Test on Insulating Tape.

electrode rods are surrounded by insulating blocks *d* and *d'* having vent holes *h* for the dissipation of the gases generated by breakdown. These insulating blocks are faced with soft rubber washers *e* which can be detached and replaced as necessary.

The lower electrode assembly is lined up with the upper electrode assembly by centering springs *j*, the position of which is adjustable. This lower assembly is also free to rock very slightly on a single ball support. This insures perfect contact and equalisation of pressure when the electrode assemblies come together.

The upper electrode assembly is normally held clear of the lower

assembly by two small springs so that tape may be readily inserted or withdrawn or moved to a new position of test. The piston *b* is smooth, without rings, and permits just enough leakage of air so that the pressure may be quickly adjusted and readily held at any desired value below the maximum available.

Where compressed air is not available, pressure may be exerted by a hand-operated lever attached to the upper, or movable, electrode assembly.

A2. Multiple Electrode Tester. Another form of tester, known as the multiple-electrode type, clamps a long piece of tape under pressure between two insulating blocks and has ten sets of electrodes spaced at intervals along the test specimen.

TENTATIVE SPECIFICATION FOR BLACK BIAS-CUT VARNISHED CLOTH TAPE USED FOR ELECTRICAL INSULATION *

A.S.T.M. Designation D 373—39 T

ISSUED, 1933 ; REVISED, 1934, 1936, 1937, 1939

This Tentative Standard of the American Society for Testing Materials is, under its regulations, subject to the annual revision. Suggestions for revision should be addressed to the Society,
260 S. Broad Street, Philadelphia, Pa.

1. Scope. These specifications cover black seamless bias-cut varnished cloth tapes 7–12 mils in thickness to be used for insulating busbars, joints and terminals of electric wires and cables, and other electrical apparatus connections.

Note : Orders for material under these specifications shall include the following information :—

The desired nominal thickness, width, and length (Section 10) ;
Type of surface, greasy or tacky (Section 3) ;
Type of packing, dry or oil (Section 12) ;
Number of rolls in packing (Section 12 (b) and (c) ; and
Marking on package (Section 13).

2. Manufacture. (a) *Materials.* The cloth and the number of coats of varnish applied shall be such as to produce a product which will meet the requirements of these specifications.

(b) *Splices.* Splices are those joints made by the manufacturer

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of the untreated cloth. Splices shall not occur more than once in each roll, except that rolls having a length of 6 yards or less shall contain no splices.

(c) *Defects.* In general, the tape shall be free from wrinkles, excessive pebbling, blisters and other imperfections.

3. *Surface.* Tapes are roughly divisible into two classes: "greasy" and "tacky." Greasy tapes shall have the property of sliding freely, one layer upon another, when moved easily between two fingers.

4. *Breaking Strength.* (a) The breaking strength requirement varies with the nominal thickness of the tape. Let "*t*" represent the nominal thickness in mils; then, the average breaking strength of the specimens shall be not less than $85 + (t-7)$ lb. per inch of width. If the first specimen from a roll does not conform to this requirement, tests of two additional specimens from the same roll shall be made and the average of these three tests shall conform to the above requirement. The breaking strength of any of the specimens tested shall be not less than $29 + (t-7)$ lb. per inch of width.

(b) The breaking strength of the "jointed selvages" shall be not less than 80 per cent. of the values specified in Paragraph (a).

5. *Elongation.* (a) For tapes of nominal width not less than 0.5 inch, the elongation of one specimen from each of the selected rolls shall be measured at a temperature *T* between 20° and 80° C. and shall be not less than that specified in the following table:—

Nominal Thickness	Load, lb. per inch of Tape Width	Elongation per cent.
7 mils	5	$1.7 + (T-20) \times 0.1$
Over 7 mils	6	$1.7 + (T-20) \times 0.1$

(b) The specimens tested for elongation shall be used for electrical tests as described in Section 8.

6. *Resistance to Oil.* (a) One specimen from each of the selected rolls shall be subjected to test for resistance to oil as described in the methods referred to in Section 11. The oil used shall be an insulating oil having a flash point of not less than 185° C. (275° F.) as determined by the Cleveland open cup in accordance with the Standard Method of Test for Flash and Fire Points by Means of Open Cup (A.S.T.M. Designation D 92 of the American Society for Testing Materials). The varnished film shall show no evidence

of disintegration in the oil nor flake either in the oil or on the blotter used in the test.

(b) The specimens tested for resistance to oil shall be used for electrical tests as described in Section 9.

7. Dielectric Strength, as Received. (a) Ten punctures shall be made on one specimen from each roll as received. The dielectric strength values are the puncture values in volts divided by the average of the ten thickness readings on the specimens in mils. The average of the ten dielectric strength values for each roll as received, shall conform to the requirements prescribed in Table 1. The dielectric strength values when analysed to determine the uniformity of the material shall conform to the requirements specified in Paragraphs (b) and (c).

(b) Uniformity within Roll. The deviation factor for each roll in shipment shall be not more than 0.08 when calculated as follows:

Table I
Dielectric Strength Requirements for Varnished Cloth Tape

Nominal Thickness	Dielectric Strength Minimum Average Volts per mil.		
	As Received	After Elongation	After Hot Oil
Over 10 mils	1,100	1,000	1,100
9 and 10 mils, incl. . . .	1,000	900	1,000
Under 9 mils	900	800	900

$$\text{Deviation factor of roll} = \frac{h - l}{h + l}$$

where

h = average of the five highest dielectric strength values of the roll in volts per mil, and

l = average of the five lowest dielectric strength values of the roll in volts per mil.

(c) Uniformity of Shipment. The deviation factor for each shipment shall be not more than 0.07 when calculated as follows :

$$\text{Deviation factor of shipment} = \frac{a - l}{a + l}$$

where

a = average dielectric strength of the entire shipment in volts per mil, and

l = average of the five lowest dielectric strength values of the roll in volts per mil.

8. Dielectric Strength, after Elongation. Five punctures shall be made inside the gauge length on each specimen after the elongation test specified in Section 5. The average of the five dielectric strength values for each roll shall conform to the requirements prescribed in Table 1.

9. Dielectric Strength, after Hot Oil. Five punctures shall be made on each specimen after the test for resistance to oil specified in Section 6. The average of the five dielectric strength values for each roll shall conform to the requirements prescribed in Table 1.

10. Dimensions and Permissible Variations. (a) *Thickness.* The nominal thickness shall be specified in the purchase order. The average thickness shall be determined from ten measurements taken on a specimen before testing in accordance with Section 7. The average thickness shall not vary more than plus or minus 0.001 inch from the specified nominal thickness, and no individual measurement shall vary more than plus 0.002 or minus 0.001 inch for tapes from 5–9 mils in thickness, nor more than plus or minus 0.003 inch for tapes 10–12 mils in thickness, from the specified nominal thickness.

(b) *Width.* The nominal width shall be specified in the purchase order. Individual measurements on all the samples selected under Section 11 shall not vary more than plus or minus $\frac{1}{32}$ inch from the specified nominal width for tapes 1 inch or less in width, nor more than plus or minus $\frac{1}{16}$ inch for tapes over 1 inch in width.

(c) *Length.* The nominal length or yards per roll shall be specified in the purchase order. The measured lengths of individual rolls selected under Section 11 shall be not less than specified.

11. Methods of Testing. (a) Varnished cloth tape shall be sampled, conditioned, and tested in accordance with the Tentative Methods of Testing Varnished Cloths and Varnished Cloth Tapes Used in Electrical Insulation (A.S.T.M. Designation: D 295 of the American Society for Testing Materials).

(b) All specimens taken from a single roll shall be numbered or marked so that failures can be identified with the roll.

12. Packing. (a) The purchaser shall specify whether tape is to be supplied dry or immersed in oil.

(b) *Dry Packing.* In the case of dry tape, the purchaser shall specify the number of rolls per package and whether each roll shall be dipped or whether each package shall be dipped in a

moisture resistant wax or neither or both. The wrapping shall be secure and shall protect the contents.

(c) **Packing in Oil.** Oil-immersed tape shall be supplied in suitable oil-tight cans with easily removable lids. The purchaser shall specify the number, width and length of rolls to be supplied in each can. The type of oil used for packing shall be subject to the approval of the purchaser.

13. Marking. The purchaser shall specify the marking desired on each package or can ; unless the marking is definitely specified the package shall conform with the usual trade customs.

14. Inspection and Testing. The material shall be inspected and tested within three weeks of its receipt by the purchaser.

15. Rejection. (a) The purchaser reserves the right to reject any part of the shipment that does not conform to the requirement for packing and marking as specified in Sections 12 and 13.

(b) The failure of a sample roll to conform to the requirements of one or more of the sections enumerated under Paragraphs (c) and (d) shall be counted as only one roll failure.

(c) The failure of 35 per cent. or more of the sampled rolls to conform to the requirements of Sections 2 (b) and (c), 3 and 10 shall constitute cause for rejection of the entire shipment without further tests.

(d) The failure of 50 per cent. or more of the sampled rolls to conform to the requirements of Sections 4, 5, 6, 7, 8 and 9 shall constitute cause for rejection of the entire shipment. (See Explanatory Note.)

16. Claims. Rejection claims shall be made to the seller in writing within four weeks of receipt of the material by the purchaser. The results of tests made by the purchaser on which rejection is based shall be furnished to the seller, who shall, within one week of receipt of all such claims, either agree to satisfy the claim or send a representative to the plant of the purchaser to re-sample the shipment. Samples so selected shall be sealed and submitted to an umpire, mutually agreeable to the purchaser and seller, whose decision should be final.

17. Settlement of Claims. The expense of the umpire tests shall be paid by the loser. In case of rejection being established, the seller shall pay the freight both ways on the rejected material.

Explanatory Note

The following illustrates a convenient method of recording failures of sampled rolls :—

Roll No.	Failures under Sections					Roll Failures
	2 (b)	2 (c) 3	10 (a)	10 (b)	10 (c)	
1			×			×
2			×	×		×
3						
4						
5						
6	×			×	×	×
7						
8						
9						
10						

Total rolls sampled—10.

Total failures—8 rolls.

Thirty per cent. of the rolls failed, therefore this shipment passes Section 15 (c).

AMERICAN STANDARD SPECIFICATION FOR VARNISHED CLOTH INSULATION FOR LEAD-COVERED OR BRAID-COVERED POWER CABLE

C.8.13—1942 *

Note. The requirements prescribed herein are identical with those for insulation in the Insulated Power Cable Engineers Association Specifications for Varnished Cambric Insulated Cables, 4th Edition, July, 1939 (also a standard of the National Electrical Manufacturers Association.)

1. Scope

1. 1. These specifications are intended to apply to varnished cloth insulation in metallic-covered and/or braided cable, which is to be used for the transmission and distribution of electrical energy in underground, aerial, or indoor cable systems within following voltage limits: for non-shielded, multiple-conductor cable not over 17,000 volts between conductors; for single-conductor and shielded cable operating on an underground neutral system, not over 17,000 volts between conductors; for single-conductor and shielded cable operating on a grounded neutral system, not over 28,000 volts between conductors.

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Cable used for pressure measurements and for fire alarm, signalling, telephone service and similar purposes is not included. (Cable for special usages such as so-called vertical risers in buildings exceeding 100 feet in height, bore-hole cable, and submarine cable require special consideration and should be referred to the manufacturer for recommended design.)

2. Materials for Insulation

2. 1. Varnished Cloth. 2.1.1. *General.* The varnished cloth insulation shall consist of a high grade of varnished cloth substantially free from blisters, or other imperfections, and shall meet the requirements herein specified.

2. 1. 2. *Cloth.* The cloth shall be uniformly woven cotton. The number of threads per inch shall be not less than 60×55 .

2. 1. 3. *Varnish Coating.* The varnish coating shall be pliable and shall not show cracks readily visible to the unaided eye when the varnished cloth is doubled upon itself.

2. 1. 4. *Thickness.* The finished varnished cloth shall be of uniform thickness between the following limits :—

Minimum average thickness : 6 mils.

Maximum average thickness : 13 mils.

Allowable variation of individual tapes : 20 per cent. plus or minus, but not to exceed 1.5 mils.

2. 1. 5. *Tensile Strength.* The tensile strength (measured lengthwise) of the varnished cloth before application to the cable shall be not less than 8,000 pounds per square inch. For samples taken after application to a cable, it shall be not less than 2,400 pounds per square inch.

2. 1. 6. *Dielectric Strength.* Dielectric strength tests of the varnished cloth to be used in the manufacture of the cable shall meet requirements specified below.

The dielectric strength tests shall be made on ten rolls of varnished cloth for each 10,000 feet of cable or fraction thereof manufactured, except that no tests shall be made on items of less than 5,000 feet unless specifically requested by the purchaser at the time of asking for quotations on the cable. The purchaser may select the rolls from the manufacturer's stock or from material in the process of manufacture as generally representative of the cloth used in the manufacture of the cable on his order. Five tests at room temperature and five tests at 85°C , shall be made on each roll of tape so selected,

If the purchaser so desires he may, in lieu of the above tests, prescribe that the tests be made on cloth from the finished cable. In this case the total number of samples shall be as indicated above. Not less than five (unless the cable has fewer than five tapes in which case all tapes shall be taken), nor more than ten tapes shall be taken from any one reel of cable. The samples shall be selected to be as representative as possible of all of the tapes used. Five tests at room temperature and five tests at 85°C. shall be made on each of the tapes so selected. The starting voltage and the required breakdown strength shall be based on the values shown below :—

Dielectric Strength Tests on Individual Tapes

Cloth from	Temperature (° C.)	Starting Voltage (Stress, Volts per mil)	Breakdown Voltage (Stress, Volts per mil)
Rolls . . .	Room	850	1,000
Rolls . . .	85° C	600	750
Cable . . .	Room	650	800
Cable . . .	85° C	475	625

The starting voltage shall be adjusted to the nearest even 250-volt step for varnished cloth having a nominal thickness of 8 mils or less and to the nearest even 500-volt step for varnished cloth having a nominal thickness greater than 8 mils. Voltage shall be increased by the following increments :—

The tapes of 8 mils nominal thickness or less : 250 volts.

The tapes of over 8 mils nominal thickness : 500 volts.

The average breakdown stress for the five tests on any one tape, if samples are selected from rolls of varnished cloth, or for all tests on all of the tested tapes from any one reel of cable if the samples are taken from finished cable, shall be not less than that indicated above. Tests at each temperature shall be not considered separately.

If samples taken from rolls of tape fail to pass the above prescribed tests, samples shall be taken from every length of cable represented by these samples. Not less than five (unless the cable has fewer than five tapes, in which case all tapes shall be taken), nor more than ten tapes shall be taken from each length of cable, and five tests at room temperature and five tests at 85° C. shall be made on each tape. The samples shall be selected to be as representative as possible of all of the tapes used. The average of all tests on all tested tapes from any one reel of cable shall be

considered the average breakdown stress and shall be not less than the appropriate value given above. Tests at each temperature shall be considered separately. Any length from which such samples are taken and tested and on which samples fail to meet the requirements indicated for varnished cloth taken from finished cable shall be rejected.

2. 1. 7. *Effect of Heat.* After the varnished cloth has been placed in petrolatum, heated to 150° C. and maintained at that temperature for fifteen minutes and then removed and allowed to cool to room temperature, the varnish coating shall not be materially softer or more tacky than before being placed therein.

2. 2. *Compound.* The compound applied between the layers of varnished cloth shall be a viscous, non-hardening compound of slow drying characteristics and of such a nature as to have no deleterious effect on the varnished cloth or conductor.

3. Workmanship

3. 2. *Taping.* The varnished cloth, cut into tapes of suitable width, shall be wound around the conductors helically, evenly and substantially free from wrinkles. Where belt insulation is prescribed, it shall be applied in a similar manner. The edges of the tape of successive layers of tape shall be staggered.

3. 3. *Compound.* The compound shall be applied between alternate layers of varnished cloth so as to exclude, as far as practicable, air and moisture, and form with the varnished cloth a firm, semi-inflexible wall of insulation.

BLACK AND YELLOW BIAS-CUT VARNISHED CLOTH TAPE

PUBLICATION No. 38—50, APRIL, 1938 *

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

155 East 44th Street, New York, N.Y.

STANDARD No. 1—BLACK BIAS-CUT VARNISHED CLOTH TAPE

Scope. These standards cover black bias-cut varnished cloth tapes 7, 10 and 12 mils in thickness to be used for insulating bus-

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bars, joints and terminals of electrical wires and cables, other electrical connections and electrical apparatus.

VF5-10 Ordering Information. Orders for material under these standards shall include the following information :—

The desired nominal thickness, width and length—covered by standards VF5-20, VF5-25 and VF5-80.

Type of packing, dry or oil—covered by standards VF5-100, VF5-105, and VF5-110.

Number of rolls in package—covered by standards VF5-105 and VF5-110.

Marking on package—covered by standard VF5-115.

Adopted Standard 10-4-1986.

Dimensions and Permissible Variations

VF5-20 Thickness. The nominal thickness shall be specified in the purchase order. The average thickness shall be determined from the ten measurements taken on a specimen before testing in accordance with standard VF5-60. The average thickness shall vary not more than 12 per cent. from the specified nominal thickness and no individual measurement shall vary more than 20 per cent. from the specified nominal thickness.

Adopted Standard 10-4-1986.

VF5-25 Width. The nominal width shall be specified in the purchase order. Individual measurements on all the samples selected under standard VF5-85 shall vary not more than plus or minus $\frac{1}{8}$ inch from the specified nominal width.

Adopted Standard 10-4-1986.

VF5-30 Length. The nominal length of yards per roll shall be specified in the purchase order. The measured lengths of individual rolls selected under standard VF5-85 shall be not less than that specified.

Adopted Standard 10-4-1986.

Physical Properties and Tests

VF5-35 Methods of Testing. (a) Varnished cloth tape shall be sampled, conditioned and tested for dimensions and quality in accordance with the Tentative Methods of Testing Varnished Cloths and Varnished Cloth Tapes Used in Electrical Insulation (Designation : D 295—87T of the American Society for Testing Materials).

(b) All specimens taken from a single roll shall be numbered or marked so that failures can be identified with the roll.

Adopted Standard 12-10-1987.

VF5-45 Tensile Breaking Strength. The average tensile breaking strength of the specimens shall be not less than 85 lb. per inch of width. If the first specimen from a roll does not conform to this requirement, tests of two additional specimens from the same roll shall be made. Then the average of the three tests shall conform to the above requirements. The tensile breaking strength of any of the tests made shall be not less than 80 lb. per inch of width.

Adopted Standard 10-4-1986.

VF5-50 Elongation. (a) For tapes of nominal width not less than 0.5 inch, the elongation of one specimen from each of the selected rolls shall be measured at a temperature T between 20° and 80° C., and shall be not less than that specified in the following table :—

Nominal Thickness (mils)				Load, lb. per Inch of Tape Width	Elongation Per Cent.
	7	.	.	6	$1.7 + (T-20) \times 0.1$
Over	7	.	.	5	$1.7 + (T-20) \times 0.1$

(b) The specimens tested for elongation shall be used for electrical tests as described in standard VF5-65.

Adopted Standard 10-4-1986.

VF5-55 Resistance to Oil. (a) One specimen from each of the selected rolls shall be subjected to test for resistance to oil described in the test methods referred to in standard VF5-85. The oil shall be an insulating oil having a flash point of not less than 180° C. (266° F.) as determined by the Cleveland open cup in accordance with the specifications of the American Standards Association, Standard Method of Test for Flash and Fire Points by Means of Open Cup, Z116 (A.S.T.M. Designation : D 92-88 of the American Society for Testing Materials). The varnished film shall show no evidence of disintegration in the oil nor flake either in the oil or on the blotter used in the test.

(b) The specimens tested for resistance to oil shall be used for electrical tests as described in standard VF5-70.

Adopted Standard 10-4-1986.

VF5-60 Dielectric Strength as Received. Ten punctures shall be made on one specimen from each roll as received. The dielectric strength values are the puncture values in volts divided by the average of the ten thickness readings on the specimens in mils. The average of the ten dielectric strength values for each roll as received shall be not less than that given below :—

Dielectric Strength as Received	
Nominal Thickness (mils)	Average Volts per Mil
12	1,100
10	1,000
7	900

Adopted Standard 10-4-1986.

VF5-65 Dielectric Strength after Elongation. Five punctures shall be made inside the gage length on each specimen after elongation test specified in standard VF5-50. The average of the five dielectric strength values for each roll shall be not less than that given below :—

Dielectric Strength after Elongation	
Nominal Thickness (mils)	Average Volts per Mil
12	1,000
10	900
7	750

Adopted Standard 10-4-1986.

VF5-70 Dielectric Strength after Hot Oil. Five punctures shall be made on each specimen after the test for resistance to oil specified in standard VF5-55. The average of the five dielectric strength values for each roll shall be not less than that given below :—

Dielectric Strength after Hot Oil Test

Nominal Thickness (mils)	Average Volts per Mil
12	950
10	850
7	750

Adopted Standard 10-4-1986.

Manufacture

VF5-80 Cloth and Varnish. The cloth and the number of coats of varnish applied shall be such as to produce a product which will meet the requirements of these standards.

Adopted Standard 10-4-1986.

VF5-85 Defects. In general, the tape shall be free from wrinkles, excessive pebbling, blisters and other imperfections.

Adopted Standard 10-4-1986.

VF5-90 Splices. Splices shall occur not more than once in each roll of 72 yards or less except that rolls having a length of 6 yards or less shall contain no splices.

Adopted Standard 12-10-1987.

Packing and Marking

VF5-100 Packing. The purchaser shall specify whether tape is to be supplied dry or immersed in oil.

Adopted Standard 10-4-1986.

VF5-105 Dry Packing. In the case of dry tape, the purchaser shall specify whether each roll shall be dipped or whether each package shall be dipped in a moisture-resistant wax. The wrapping shall be secure and shall protect the contents.

Adopted Standard 12-10-1987.

VF5-110 Packing in Oil. Oil-immersed tape shall be supplied in suitable oil-tight cans with easily removable lids. The purchaser shall specify the number, width and length of rolls to be supplied in each can.

Adopted Standard 10-4-1986.

VF5-115 Marking. The purchaser shall specify the marking desired on each package or can ; unless the marking is definitely specified, the package shall conform with the usual trade customs.

Adopted Standard 10-4-1986.

Inspection and Rejection

VF5-120 Rejection. (a) The purchaser shall have the right to reject any part of the shipment that does not conform to the requirements for packing and marking as specified in standards VF5-105, VF5-110 and VF5-115.

(b) The failure of a sample roll to conform to the requirements of one or more of the standards enumerated under Paragraphs (c) and (d) shall be counted as only one roll failure.

(c) The failure of 85 per cent. or more of the sampled rolls to conform to the requirements of the following standards shall constitute cause for rejection of the entire shipment without further tests :—

VF5-20—Thickness.

VF5-25—Width.

VF5-30—Length.

VF5-85—Defects.

VF5-90—Splices.

(d) The failure of 50 per cent. or more of the sampled rolls to conform to the requirements of the following standards shall constitute cause for rejection of the entire shipment :—

VF5-45—Tensile Breaking Strength.

VF5-50—Elongation.

VF5-55—Resistance to Oil.

VF5-60—Dielectric Strength as Received.

VF5-65—Dielectric Strength after Elongation.

VF5-70—Dielectric Strength after Hot Oil.

Adopted Standard 12-10-1987.

VF5-125 Claims. Rejection claims shall be made to the seller in writing within four weeks of receipt of material by the purchaser. The results of tests made by the purchaser on which rejection is based shall be furnished to the seller, who shall either agree to satisfy the claim or agree to re-sample the shipment. Samples so selected shall be sealed and submitted to an umpire, mutually agreeable to the purchaser and seller, whose decision shall be final.

Adopted Standard 10-4-1986.

VF5-130 Settlement of Claims. The expense of the umpire tests shall be paid by the loser. In the case of rejection being established, the seller shall pay the freight both ways on the rejected material.

Adopted Standard 10-4-1936.

STANDARD No. 2

YELLOW BIAS-CUT VARNISHED CLOTH TAPE

Scope. These standards cover yellow bias-cut varnished cloth tapes 7, 10 and 12 mils in thickness to be used for insulating electrical connections and electrical apparatus.

VF6-10 Ordering Information. Orders for material under these standards shall include the following information :—

The desired nominal thickness, width and length—covered by standards VF6-20, VF6-25, VF6-30.

Packing—covered by standard VF6-105.

Marking on package—covered by standard VF6-115.

Adopted Standard 12-10-1937.

Dimensions and Permissible Variations

VF6-20 Thickness. The nominal thickness shall be specified in the purchase order. The average thickness shall be determined from the ten measurements taken on a specimen before testing in accordance with standard VF6-60. The average thickness shall vary not more than 12 per cent. from the specified nominal thickness and no individual measurement shall vary by more than 20 per cent. from the specified nominal thickness.

Adopted Standard 12-10-1937.

VF6-25 Width. The nominal width shall be specified in the purchase order. Individual measurements on all the samples selected under standard VF6-35 shall vary not more than plus or minus $\frac{1}{32}$ inch from the specified nominal width.

Adopted Standard 12-10-1937.

VF6-30 Length. The nominal length of yards per roll shall be specified in the purchase order.

Adopted Standard 12-10-1937.

Physical Properties and Tests

VF6-35 Methods of Testing. (a) Sampling. The sample shall consist of at least three rolls and shall be so selected as to be

reasonably representative of the average quality of the varnished cloth tapes in the shipment. One sample roll shall be taken from each package selected at random and shall represent not more than 100 rolls of tape in the shipment.

(b) Varnished cloth tape shall be conditioned and tested for dimensions and quality in accordance with the Tentative Methods of Testing Varnished Cloths and Varnished Cloth Tapes Used in Electrical Insulation (Designation : D 295—37T of the American Society for Testing Materials).

Adopted Standard 12-10-1937.

VF6-45 Tensile Breaking Strength. The average tensile breaking strength shall be not less than 80 lb. per inch of width

Adopted Standard 12-10-1937.

VF6-50 Elongation. (a) For tapes of nominal width not less than 0.5 inch, the elongation of one specimen from each sample roll shall be measured at a temperature between 20° and 80° C., and shall be not less than 1.5 per cent. when tested with a load of 6 lb. per inch width for a period of thirty-five minutes.

(b) The specimens tested for elongation shall be used for electrical tests as described in standard VF6-65.

Adopted Standard 12-10-1937.

VF6-60 Dielectric Strength as Received. Ten punctures shall be made on one specimen from each sample roll in the condition as received. The dielectric strength values are the puncture values in volts divided by the average of the ten thickness readings on the specimen in mils. The average of the ten dielectric strength values for each roll as received shall be not less than that given below :—

Dielectric Strength as Received

Nominal Thickness (mils)	Average Volts per Mil
12	900
10	800
7	700

Adopted Standard 12-10-1937.

VF6-65 Dielectric Strength after Elongation. Five punctures shall be made inside the gage length on each specimen after the

elongation test specified in standard VF6-50. The average of the five dielectric strength values for each roll shall be not less than that given below :—

Dielectric Strength after Elongation

Nominal Thick- ness (mils)	Average Volts per Mil
12	650
10	575
7	500

Adopted Standard 12-10-1937.

Manufacture

VF6-80 Cloth and Varnish. The cloth and number of coats of varnish applied shall be such as to produce a product which will meet the requirements of these standards.

Adopted Standard 12-10-1937.

VF6-85 Defects. In general, the tape shall be free from wrinkles, excessive pebbling, blisters and other imperfections.

Adopted Standard 12-10-1937.

VF6-90 Splices. Splices shall occur not more than once in each roll of 72 yards or less except that rolls having a length of 6 yards or less shall contain no splices.

Adopted Standard 12-10-1937.

Packing and Marking

VF6-105 Packing. The purchaser shall specify whether each roll shall be dipped or whether each package shall be dipped in moisture-resistant wax. The wrapping shall be secure and shall protect the contents.

Adopted Standard 12-10-1937.

VF6-115 Marking. The purchaser shall specify the marking desired on each package ; unless the marking is definitely specified, the package shall conform with the usual trade customs.

Adopted Standard 12-10-1937.

Inspection and Rejection

VF6-120 Rejection. Failure of any part of the shipment to comply with these specifications shall be cause for complaint to be adjusted by the supplier.

Adopted Standard 12-10-1987.

VF6-125 Claims. Complaints shall be made to the seller in writing within four weeks of receipt of material by the purchaser.

Adopted Standard 12-10-1987.

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